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A Study of Babylonian Observations of Planets Near Normal Stars

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Abstract

The present paper is an attempt to describe the observational practices behind a large and homogeneous body of Babylonian observation reports involving planets and certain bright stars near the ecliptic ("Normal Stars"). The reports in question are the only precise positional observations of planets in the Babylonian texts, and while we do not know their original purpose, they may have had a part in the development of predictive models for planetary phenomena in the second half of the first millennium B.C.

The paper is organized according to the following topics: (I) Sections 1–3 review the format of the observations and the texts in which they are found; (II) Sections 4–6 discuss the composition of the Normal Star list; (III) Sections 7–8 concern the orientation of the reported celestial directions from star to planet; (IV) Sect. 9 concerns the relationship between the reported distances and the actual angular distances between planet and star; and (V) Sect. 10 discusses the reports of planetary stations, which are the most common reports giving precise locations of planets when they are not near their closest approach to stars, and draws some brief general conclusions about the utility of the Babylonian observations for estimating planetary longitudes and calibrating models in antiquity. [1]

1. Context

In Babylonian mathematical astronomy, the locations of the sun, moon, and planets along the zodiacal belt are specified as longitudes, measured in degrees within twelve equal zodiacal signs, this being the origin of the Greek and modern conventions of celestial longitude. The longitudes recorded in the tabular texts of this astronomy were calculated according to arithmetical algorithms that model solar, lunar, or planetary motion between successive dates of interest such as consecutive syzygies or stationary points. These sequences of computed longitudes must in all cases have started out from longitudes derived (albeit perhaps at some remove) from observation, and moreover the original derivation of the algorithms themselves must have involved some observation of longitudes. No known text directly identifies these observations, or how they were made.

[1] I wish to thank Lis Brack-Bernsen, John Britton, Peter Huber, Hermann Hunger, Teije de Jong, Norbert Roughton, John Steele, and Noel Swerdlow for comments on drafts of the paper, for access to work before publication, and for help in various forms.

In the Babylonian observational records, on the other hand, precise positions of the moon and planets are usually specified in relation to stars, using units of astrometric distance called cubits (KÙŠ) and fingers (SI) and indications of direction such as north, south, east, or west, but also "above," "below," "in front of," or "behind." The stars used in these reports are known in modern scholarship as Normal Stars ("normal" meaning "standard," reflecting the original German terminology *Normalstern*, introduced by Epping).[2]

Observational texts and almanacs also record dates on which a planet entered a zodiacal sign. These are effectively indications of longitude, since when a planet enters a sign in direct motion it is at 0° in that sign, and when it enters a sign in retrograde motion it is at 30° in that sign (or equivalently 0° in the next sign). A rule of fundamental importance relating these sign-entries to Normal Star records is due to Huber.[3] Huber collated the planetary data from two pairs of Almanacs (texts that contain, among other things, predictions of planetary sign-entries) and Normal Star Almanacs (texts that contain predicted planetary positions relative to Normal Stars) that happened to cover the same years, and noticed that the dates of entry of planets into three particular zodiacal signs (Gemini, Cancer, and Aquarius) in the Almanacs coincided exactly with the dates when the Normal Star Almanacs reported that the same planets were "above" or "below" three particular Normal Stars (ζ Tauri, β Geminorum, δ Capricorni). Since both Almanacs and Normal Star Almanacs are believed to have been composed entirely of predicted data rather than from direct observations, the coincidences show that the two kinds of event were regarded as equivalent by the Babylonians, though they do not reveal conclusively whether one first forecast a Normal Star passage independently and then converted this into a date of sign-entry, or *vice versa*. Following Huber's lead I have found eleven reports of planets crossing the beginnings of Gemini, Cancer, and Aquarius in the Babylonian Diary texts on precisely the same dates when, according to the Diaries or overlapping observation texts, the planet in question was "above" or "below" the relevant Normal Star, while the only apparent instance of divergent dates appears to be affected by a textual error (Appendix 1). The significance of finding Huber's phenomenon in the Diary texts is that the Normal Star records in the Diaries seem to be mostly or entirely direct observations, so that the sign-entries must be derived from them.

If in these special situations a longitude was derived from a position relative to a Normal Star, it seems reasonable to hypothesize that in general the Babylonians had methods of estimating longitudes from Normal Star observations. Support for this hypothesis comes from two Babylonian tablets containing parts of a "star catalogue," which comprised a list of Normal Stars with their longitudes in degrees (hereafter referred to as the "Sachs catalogue" and "RSW catalogue").[4] There remain serious unresolved difficul-

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[2] Epping 1889 115.

[3] Huber 1958 193–197.

[4] Respectively BM46083 (originally published in Sachs 1952) and BM36609. BM36609 is now published in Roughton Steele, and Walker 2004 (the catalogue is Sect. 8); the same paper presents a corrected edition of BM46083 as Appendix A. Some of the texts on these two tablets were evidently the same, but the catalogue sections exhibit significant differences of detail. Note that in this paper tablets will be identified by their museum number, or by text number in the following editions: Sachs and Hunger 1988, 1989 and 1996 (Diary texts, e.g. Diary -567); Hunger 2001 (Lunar and planetary texts, e.g. H53); von Weiher 1993 and von Weiher 1998 (e.g. SpTU

ties, in particular because the Normal Stars are very unevenly distributed and because not all sign boundaries would have had a Normal Star in close proximity. Very likely there existed rules for interpolating or extrapolating longitudes on the basis of simple short-term patterns of planetary motion, but we as yet know nothing of these.

Besides the presumed use of Normal Star observations by the Babylonians themselves to determine longitudes, we know that Greek astronomers had access to some of the planetary Normal Star observations and attempted to reduce them to ecliptic coordinates for theoretical purposes. Three Babylonian Normal Star observations appear in Greek translation in Ptolemy's *Almagest* (unfortunately, none of them coincides with a preserved Babylonian tablet); these are instances in which the planet in question (Mercury or Saturn) was reported as being a stated distance above or below a Normal Star, and Ptolemy interprets this to mean that the planet was at the same longitude as the star.[5] A recently discovered marginal comment in some manuscripts of the *Almagest* indicates that Ptolemy wrote another work, now lost, in which he apparently adduced Normal Star observations of Venus to investigate that planet's latitudinal motion and visibility phenomena.[6]

2. Citations of Normal Stars in observation texts

The Normal Stars are cited in two distinct ways in the observation texts. One type of record, which I will refer to as a "positional," asserts that a heavenly body was in a particular situation relative to a Normal Star at the occasion when a conspicuous phenomenon relating to the heavenly body occurred. The phenomena in question are lunar eclipses for the moon, and stations and—very rarely – first appearances for the planets.[7] The second (and much more common) type of record, which I will refer to as a "passage," asserts that a heavenly body was in a particular situation relative to a Normal Star on a stated date, without reference to any phenomenon. Passages are reported for the moon as well as the five planets.

The following are two examples of planetary passages:

(Diary -321 Rev. 21′)
GE_6 21 USAN *dele-bat e* SI_4 ⌜6⌝ SI *dele-bat* 2 SI *ana* ŠÚ LAL
Night of the 21st, first part of the night, Venus was 6 fingers above Lisi, Venus being 2 fingers back to the west.

(Diary -324 B Rev. 2)
[GE_6 4] SAG GE_6 . . . *dele-bat ár* GÌR *ár šá* UR-A 2 SI *dele-bat* 2 SI *ana* ULÙ SIG
[Night of the 4th,] beginning of the night. . ., Venus was 2 fingers behind the rear foot of the lion, Venus being 2 fingers low to the south.

Here we see two alternative specifications: (a) a statement of how far (in cubits and fingers) the heavenly body is north ("above") or south ("below") of the Normal Star,

4.268). The longitude assigned in the RSW catalogue to δ Cap is Capricorn 30°, consistent with the association of this star with the sign boundary.

5 Ptolemy, *Almagest* 9.7 and 11.7, translations in Toomer 1984 452 and 541.

6 Jones 2004.

7 Even the brightest stars are seldom visible near a planet at its first appearance.

followed by a statement of how far the heavenly body is "back to the west" or has "passed to the east"; and (b) a statement of how far the heavenly body is west ("in front of") or east ("behind") the Normal Star, followed by a statement of how far the heavenly body is "high to the north" or "low to the south." There does not appear to be a fixed rule to decide which version of the formula to use, though the pattern "above/below" followed by "east/west" is more common. The usual directional expressions are as follows:

e	above
SIG	below
ár	behind
ina IGI	in front of
ana SI NIM	high to the north
ana ULÙ SIG	low to the south
ana NIM DIB	passed to the east
ana ŠÚ LAL	back to the west

Note that "behind" and "in front" are stated in terms of the order of rising and setting, so that "behind" means eastward, whereas "passed to the east" and "back to the west" are stated in terms of the normal direction of progress of the heavenly bodies.

Very often only the first part of either formula is used, that is, we are told only that the heavenly body is a certain distance "above" or "below" the star, or only that it is a certain distance "in front of" or "behind" the star. Among the reports of planetary passages, the simple "above/below" formula predominates, whereas simple "in front of/behind" reports are rare. Supplementary indications of distance east or west, which are comparatively few, mostly pertain to passages of Venus and, to a lesser extent, Mercury. (In fact, since these planets typically progress more than 1° per day and are visible only for a brief while near sunset or sunrise, an observation when the planet is directly "above" or "below" a particular star – no matter what precisely these terms mean – would often have been impossible.) The sparsity of reporting of distances east or west suggests that the primary interest of the observers was in reporting the date when the planet was as nearly as possible directly "above" or "below" the Normal Star.

The following are examples of positionals from reports of lunar eclipses and planetary phenomena. The structure of the formula is basically the same as for the passages.

BM41129 (Hunger 5.20) Rev. 4–5
2 KÙŠ ⌜*ár*⌝ SA$_4$ *šá* ABSIN 1 KÙŠ *ana* SI ⌜NIM⌝ KA×MI
2 cubits behind the bright star of the furrow, 1 cubit high to the north, it was eclipsed.

Diary -141 C Obv. 20
[E]N 12 MÚL-BABBAR *ana* ŠÚ *ki* UŠ- *a* 3 KÙŠ *ina* IGI RÍN *šá* ULÙ MÚL-BABBAR 1 [KÙŠ *ana* SI NIM UŠ]

Until the 12th, when Jupiter became stationary to the west, [it became stationary] 3 cubits in front of the southern part of the scales, Jupiter being 1 [cubit high to the north.]

Diary -163 C$_2$ Rev. 4
10 GU4-UD *ina* NIM *ina* MÁŠ 3 KÙŠ *á*[*r* SI MÁŠ . . . IGI]

The 10th, Mercury's [first appearance] in the east in Capricorn, 3 cubits behind [the horn of the goat-fish.]

We have many positionals and passages in which the planet's position is reported relative to another planet instead of a star, a practice that would not have been conducive to determining longitudes. Moreover, positionals sometimes specify only the direction without the distance, and frequently the locations of planets at stations and (especially) first and last visibilities is indicated only with respect to a constellation or zodiacal sign ("in front of the chariot," "in the scorpion," etc.). Thus there were many observations from which it would not have been possible to extract a longitude.

3. Texts and collections of data used in this paper

Reports of observations of planets in relation to stars are preserved in three varieties of text, known conventionally as Astronomical Diaries, Excerpt Texts, and Goal-Year Texts.[8] In the Diaries, the planetary observations are recorded as part of night-by-night reporting of astronomical phenomena and weather covering several months of a single year. Excerpt Texts give observations of a single planet covering several consecutive years. Goal-Year Texts have sections for each of the planets, and each section covers a single year. The dated or datable Diaries have been edited in Sachs and Hunger 1988, 1989 and 1996, and most of the Excerpt Texts in Hunger 2001. Few Goal-Year Texts have been edited as yet; Sachs 1955 provided a catalogue of Goal-Year Texts and hand copies of many tablets.[9] The Diaries, Excerpts, and Goal-Year Texts certainly originate in the same observational milieu, although reports of the same event in different tablets give different details often enough to show that there did not exist a single authoritative observational archive from which all extant tablets derived their contents.[10] The great majority of the observational texts are known or presumed to come from Babylon, while a handful come from Uruk or Nippur.

This paper is chiefly concerned with analysis of the planetary observation reports from the late fifth century B.C., when we begin to have a fairly steady supply of planetary reports, to the end of the surviving observation records in the first century B.C. Throughout this interval of close to four centuries, the general pattern of observing and reporting (e.g. the choice and nomenclature of stars and the units of measure) were fairly stable. If there were significant local difference in observational practice between Babylon and other sites, they are not obvious to superficial inspection; however, I have chosen to restrict consideration to texts from Babylon in the statistical examination of the observations. In Appendix 5 I describe qualitatively the character of the planetary

[8] The classification and nomenclature for the observational texts is due to Sachs 1948; for brief explanations see Hunger 1999.

[9] Excerpt Texts not in Hunger 2001 but containing Normal Star observations include A3456 (edited in Hunger 1988), BM76738 (edited in Walker 1999), SpTU 4.171 (edited in von Weiher 1993), and SpTU 5.268 (edited in von Weiher 1998). For a bibliography of editions of Goal-Year Texts see Hunger 1999 167–173 (to which may be added Hunger 1999, 88–94).

[10] The relationship between the texts is discussed by Hunger 1999 and Hunger and Pingree 1999, 143, 167–173, and 173–181.

reports in the older texts and those from Uruk and Nippur. My general impression is that, while observations of distances of planets in cubits and fingers above, below, behind, and in front of bright stars were already being made in the early seventh century, the list of Normal Stars became standardized only in the course of the fifth century, with some refinements that will be discussed below about the middle of the fourth century.

The discussions of Babylonian planetary observations in the remainder of this paper are based primarily on two collections of data derived from the Babylonian observation records. Collection A consists of dated planetary passages of Normal Stars in the reconstructed list, and collection B of stations of Mars, Jupiter, and Saturn where the planet's position was reported relative to a Normal Star in the reconstructed list. I have chosen not to include lunar passages and eclipses in this study (except insofar as they pertain to the identification of Normal Stars), both because we cannot fix the times closely enough to get accurate positions, and because the breadth of the moon's disk introduces further uncertainty in the measurements. I have also not made use of reports of planetary passages by other planets, or stations and first visibilities located relative to other planets. The texts from which the reports in Collections A and B were extracted include:

a) all Diary texts in Sachs and Hunger 1988, 1989 and 1996 from Diary −418 on (614 passages and 60 stations);
b) planetary excerpt texts in Hunger 2001: H59–61, H64–73, H76–81, and H83 (461 passages and 58 stations); and
c) 41 Goal-Year texts (452 passages and 42 stations)[11]

These texts include most of the observation reports of the relevant kinds from Babylon that are known to exist, and unless a large new body of tablets becomes available through excavations, it is unlikely that we will ever be able to compile a substantially larger body of planetary data for the period from the late fifth century B.C. on.[12]

In collection A reports were included if the Babylonian date of the report is either preserved (even if the reading is marked as uncertain in the edition), can be restored exactly, or, in the case of the outer planets, can be restored within a small margin of uncertainty (±2 days for Saturn, ±1 day for Jupiter, ±1 day for Mars). Reports with

[11] I am deeply indebted to Hermann Hunger for making available to me preliminary transcriptions of these Goal-Year Texts in advance of his forthcoming edition, as well as for providing me with computer-searchable files of the Diaries. The Goal-Year Text transcriptions may differ in some readings from the texts as they will appear in print, but discrepancies should not significantly affect the conclusions of this paper.

[12] Data for Collections A and B are currently accessible at http://www.chass.utoronto.ca/~ajones/normal_stars. Aside from the early texts, I excluded the following texts: Diary -440 (redated by Koch 1992 to −381; it contains a single usable passage report), H53 (redated in Appendix 4 to within the period under consideration, but some uncertainty may linger), H56 (mostly earlier than the period under consideration), H63 (presumed to be from Nippur), H82 (presumed to be from Uruk; dates of Normal Star passages exhibit large systematic errors, and are presumably predictions), and A3456 (presumed to be from Uruk). Six consecutive passages of Venus at the beginning of the section for that planet in BM 34048 (Goal-Year text for SE 135) show large systematic errors, and have been omitted as a probable intrusion of observations from earlier goal-year cycles.

incomplete positional information relative to the Normal Stars were included, excepting cases where a distance east or west was reported but has not been preserved. In collection B reports were included regardless of whether the date is preserved, since the planet's longitude changes only slowly near station, but reports where the distance east or west of the Normal Star is not preserved were omitted.

Dates in the reports in Diaries were converted to the Julian calendar using the dates of month-beginnings in Sachs and Hunger vols. 1–3. Dates in the other varieties of text were converted using the tables of Parker and Dubberstein (PD3).[13] On the accuracy of PD3 relative to the calendrical information in the Diaries, see Appendix 2. Longitudes of the planets were computed using the JPL ephemeris.[14] For Mars, Jupiter, and Saturn, the time of observation was assumed, with negligible loss of accuracy, to be UT 21:00, i.e. approximately midnight at Babylon. For Venus and Mercury, the time was assumed to be UT 17:00 for evening observations, and UT 1:00 for morning observations. For the stations in collection "B" the longitudes and latitudes were computed for the midnight closest to the actual station.

Errors in the observation reports (or sometimes in the modern reading of them) may affect the date, the identity of the planet or the Normal Star, or the directions, distances, and units of distance. In a very small number of instances I have admitted corrections of the reported units (cubits for fingers or vice versa) and directions (only when the reported distance is larger than 1/2 cubit).

Reports of the same passage in different texts have been included as separate items, whether the reported date is the same or different, except that when more than one Diary tablet for the same year has the same date for a passage, it is treated as a single item. Multiple records and variants are in fact very few.

Explicit indications that a passage report is a prediction rather than direct observation by a remark such as "I did not watch" are exceedingly rare: I have noticed only one in a Diary (Diary −418, Venus on Darius year II 5 VIII 2), and one in an excerpt text (H70, Jupiter on S.E. 14 IV 24); these reports were left out of collection A. While it seems unlikely that a very large fraction of the reports of passages are unmarked predictions, the occasional one may be. Stations are not infrequently indicated as predictions, and such reports were excluded from collection B.

4. The reconstructed Normal Star list

No complete inventory of the Normal Stars is known to survive in cuneiform, although the Sachs and RSW catalogues, when complete, were evidently intended as such lists. The list of thirty-two Normal Stars that scholars work with was reconstructed by Epping, Kugler, Sachs, and Hunger from the observation records and almanacs.[15] It actually comprises two clearly distinct kinds of Normal Star. Twenty-eight of the stars

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[13] Parker and Dubberstein 1956.

[14] Currently accessible at http://ssd.jpl.nasa.gov/horizons.html.

[15] The current reconstructed list Normal Stars was presented in Sachs and Hunger 1988, 17–19 and in Hunger and Pingree 1999, 148–149. The latter also reviews the history of reconstructions of the list.

Table 1. The core 28 Normal Stars

NS	SH	Name	Translation	Identification	Passages
c1	1	MÚL KUR *šá* DUR *nu-nu*	The bright star of the ribbon of the fishes	η Psc	39
c2	2	MÚL IGI *šá* SAG ḪUN	The front star of the head of the hired man	β Ari	39
c3	3	MÚL *ár šá* SAG ḪUN	The rear star of the head of the hired man	α Ari	44
c4	4	MÚL-MÚL	The bristle	Pleiades[1]	46
c5	5	*is* le_{10}	The jaw of the bull	α Tau	45
c6	6	ŠUR GIGIR *šá* SI	The northern rein of the chariot	β Tau	68
c7	7	ŠUR GIGIR *šá* ULÙ	The southern rein of the chariot	ζ Tau	56
c8	8	MÚL IGI *šá še-pít* MAŠ-MAŠ	The front star of the twins' feet	η Gem	60
c9	9	MÚL *ár šá še-pít* MAŠ-MAŠ	The rear star of the twins' feet	μ Gem	70
c10	10	MAŠ-MAŠ *šá* SIPA	The twins' star near the shepherd	γ Gem	62
c11	11	MAŠ-MAŠ IGI	The front twin star	α Gem	57
c12	12	MAŠ-MAŠ *ár*	The rear twin star	β Gem	67
c13	16	MÚL *ár šá* ALLA *šá* ULÙ	The rear star of the crab to the south	δ Cnc	44
c14	17	SAG A	The head of the lion	ε Leo	53
c15	18	LUGAL	The king	α Leo	73
c16	19	MÚL TUR *šá* 4 KÙŠ *ár* LUGAL	The small star which is 4 cubits behind the king	ϱ Leo	57
c17	20	GIŠ.KUN A	The rump of the lion	θ Leo	46
c18	21	GÌR *ár šá* A	The rear foot of the lion	β Vir	57
c19	22	DELE *šá* IGI ABSIN	The single star in front of the furrow	γ Vir	59
c20	23	SA_4 *šá* ABSIN	The bright star of the furrow	α Vir	66
c21	24	RÍN *šá* ULÙ	The southern part of the scales	α Lib	53
c22	25	RÍN *šá* SI	The northern part of the scales	β Lib	41
c23	27	MÚL *e šá* SAG GÍR-TAB	The upper star of the head of the scorpion	β Sco	40
c24	28	SI_4	(The god) Lisi	α Sco	48
c25	29	MÚL KUR *šá* KIR_4 *šil* PA	The bright star on the tip of Pabilsag's arrow	θ Oph	54
c26	30	SI MÁŠ	The horn of the goat-fish	β Cap	49

Table 1 (cont.)

NS	SH	Name	Translation	Identification	Passages
c27	31	MÚL IGI *šá* SUḪUR MÁŠ	The front star of the goat-fish	γ Cap	46
c28	32	MÚL *ár šá* SUḪUR MÁŠ	The rear star of the goat-fish	δ Cap	42

[1] This Normal Star is commonly identified as η Tauri, although there is no evidence that a specific star in the Pleiades was intended.

Table 2. Additional Normal Stars

NS	SH	Name	Translation	Identification	Passages
a1		MÚL *ár šá* MÚL-MÚL	The rear star of the Pleiades	27 Tau	(1)
a2	13	MÚL IGI *šá* ALLA *šá* SI	The front star of the crab to the north	η Cancri	9
a3	14	MÚL IGI *šá* ALLA *šá* ULÙ	The front star of the crab to the south	θ Cancri	9
a4		*zi-im šá* ŠÀ ALLA	The glow inside the crab	Praesepe	(1)
a5	15	MÚL *ár šá* ALLA *šá* SI	The rear star of the crab to the north	γ Cancri	10
a6	26	MÚL MURUB$_4$ *šá* SAG GÍR-TAB	The middle star of the head of the scorpion	δ Scorpii	18
a7		MUL SIG *šá* SAG GÍR-TAB	The lower star of the head of the scorpion	π Scorpii	0
a8		4-ÀM IGI *šá* PA *šá ana* ZA	The four front (stars) of Pabilsag which are similar to the sign ZA	γ, δ, ε, and η Sgr?	(1)
a9		4-ÀM *ár šá* PA *šá ana* ZA	The four rear (stars) of Pabilsag which are similar to the sign ZA	σ, φ, ζ, and τ Sgr?	0
a10		MÚL TUR *šá* 2 1/2 KÙŠ *ár* MÚL *ár šá* SUḪUR MÁŠ	The small star which is 2 1/2 cubits behind the rear star of the goat-fish	ι Aqr	0
a11		*qup-pu* IGI *-ú šá* GU	The front basket of the great one	φ, χ, ψ^1, ψ^2, ψ^3 Aqr?	0
a12		*qup-pu ár-ú šá* GU	The rear basket of the great one	29, 27, 33, 30 Psc?	0
a13		DUR SIM-MAḪ	The ribbon of the swallow	δ, ε, ζ Psc?	(2)

in the list are cited frequently, such that almost every time that the moon or a planet should have been observable passing by one of these stars, the passage was recorded; we will refer to these as the "core 28." The remaining four show up in the observation reports with much less regularity.

To reflect this distinction, we present the names and identifications of the core 28 in Table 1, while Table 2 gives the same information not only for the four non-core Normal Stars in the reconstructed list, but also for several other Normal Stars that for various reasons have not previously been incorporated in the reconstructed list. In both tables the stars are ordered by increasing sidereal longitude. The first column gives a new identifier for each Normal Star, while the second column gives (where applicable) the star's serial number in the reconstructed list in Sachs and Hunger 1988. The following three columns repeat from that source the transliteration and translation of the Akkadian star names[16] and their modern identifications, which are secure for all stars in the reconstructed list. As an indication of the relative frequency of their occurrence in the Babylonian observation texts, I also give the number of planetary passage reports associated with each star in the 1527 planetary passages in Collection A.[17]

5. Alternate Normal Stars

As was first pointed out by Roughton and Canzoneri (referring to the groups a8 and a9 listed below), there are also a handful of stars that show up in the observational records but have not been incorporated in the reconstructed list.[18] Among these the one that occurs most frequently in the observation reports is:

a7. MUL SIG *šá* SAG GÍR-TAB
The lower star of the head of the scorpion
π Scorpii (Hunger in Sachs and Hunger 1988, 256)

This star is cited in lunar passages but apparently never in a planetary observation, and this seems to be the only reason that it was not included in the reconstructed list.[19] In fact since the three "stars of the head of the scorpion" are at roughly the same longitude, both π Sco and δ Sco should be regarded as alternates to β Sco, such that a heavenly body's passage was sometimes reported relative to π or δ Sco when its latitude was

[16] These names are sometimes given in abbreviated form in the observation texts.

[17] The frequencies in parentheses in Table 2 represent reports that occur in the texts from which the Collection A was drawn, but that were omitted from the collection, chiefly because the passages for the stars in question are too few to be useful. Frequencies in Collection A for stars in the core 28 range from 39 to 73. There is no significant correlation of frequency with either magnitude or distance from the ecliptic; on the other hand, the highest frequencies are concentrated in the longitudinal stretch from star 6 through star 23, it is unclear why.

[18] Roughton and Canzoneri 1992. I omit from the following inventory of additional Normal Stars the star MÚL SIG *šá* SI MÁŠ, "the lower star of the horn of the goat-fish," which is attested in lunar passages in Diaries -291 (B Obv. 17′+A Obv. 25′ and B Rev. 15), −273 (B Rev. 11′), −255 (A Obv. 7 and Rev. 5'), −237 (Rev. 9), and −143 (A 26′). Hunger (note to Diary -291, in Sachs and Hunger 1988 274) initially identified this as τ Capricorni, but from Diary -255 on (Sachs and Hunger 1989) he translates the star name without identifying it. This seems in fact to be a more specific name for β Capricorni (SI MÁŠ applying to both α and β Capricorni).

[19] π Sco occurs in Diaries -300, -262, -246, -245, -226, -204, -190, -187, -170, -168, -133, -132, -130, -129, -95, -94, -93, and -77. (Graßhoff 1999, 123) lists it without comment in his table of stars and their frequency of occurrence in his collection of reports.

enough to the south to bring it closer to one of them than to β Sco.[20] With a latitude of approximately -5.2°, π Sco is so far south that it was used for lunar passage reports only when the southern limit of the moon's orbit was nearby; perhaps the more restricted latitudinal range of the planets suffices to explain the lack of preserved planetary reports involving this star.[21] In the earlier observational texts, up to about -346, passages by the "head of the scorpion" are almost always indicated without differentiating the stars, suggesting that the group of stars originally functioned as a single Normal Star.[22]

Similarly, but now not exclusively in lunar observations, a5 (γ Cnc) seems to be used as an alternate to c13 (δ Cnc), which is at roughly the same longitude, but δ Cnc was usually preferred. Again observations before the middle of the fourth century only specify passage by the "rear stars of the crab." Probably we should also regard a2 and a3 (η and γ Cnc) as rarely used alternates to δ Cnc.[23] There appear to be no instances in which even a slow planet is recorded as passing by both a front and a rear star in this quartet, although the longitudinal interval between the front and rear pairs is larger than that between stars c27 and c28 (γ and δ Cap) which are treated as distinct Normal Stars in planetary observations.

The following are two more "alternates" that have not been incorporated in the reconstructed list, respectively for the Pleiades, c4, and the Cancer group, c13 with a1–3:

a1. MÚL *ár šá* MÚL-MÚL
The rear star of the Pleiades
Attested:
BM34750 (Hunger 5.60) Rev. III 9 (station of Jupiter)
BM36751 (Hunger 5.61) Rev. III 11 (passage of Venus)
27 Tauri

a4. *zi-im šá* ŠÀ ALLA
The glow inside the crab
Attested:
Diary -322 D Rev. 11 and 20 (Passage and station of Saturn)
Praesepe (Hunger)

6. Additional Normal Stars

The other stars that are cited in a manner analogous to Normal Stars in observation texts but have not been incorporated in the reconstructed list of thirty-two stars fall

[20] In the Diary -321 Venus is reported as passing β Sco and δ Sco on consecutive days. This is the only such double report that I know of.

[21] In some years Venus can pass close by π Sco; in Collection A, however, Venus never had a latitude south of -3 when recorded as passing β or δ Sco.

[22] The RSW catalogue lists the "head of the scorpion" without differentiating the constituent stars; on the other hand the Sachs catalogue seems to have listed the "upper star of the head of the scorpion" but omitted both π Sco and δ Sco.

[23] The Sachs and RSW catalogues are missing the section containing the stars in Cancer. Section 10 of BM36609 refers to the "front stars of the crab" and the "rear stars of the crab" without differentiating the individual stars in each pair.

within the large gaps between c24 and c25 and between c28 and c1.[24] Attention was first drawn to the first two listed below by Roughton and Canzoneri. For each star or star group I summarize the reports that make use of it, and whenever possible I give an estimate of the sidereal longitude of the star or star group derived from the report. Sidereal longitudes are given according to the norm that sidereal longitude in −100 is equal to tropical longitude plus 4° 28′, since Huber found that this reasonably approximates the norm used by the Babylonians.[25] Interestingly, the RSW catalogue lists, with preserved longitudes, all the following stars or star groups except a10.[26]

a8. 4-ÀM IGI *šá* PA *šá ana* ZA
The four front (stars) of Pabilsag which are similar to the sign ZA

(Table 3)

Mean of longitudes from reports 1, 6, 7, 8, 9, 10, and 11: 247.8
Longitude according to RSW catalogue: 270 (presumed scribal error for 249)
Estimated latitude from report 10: −5.2

The cuneiform sign ZA, comprising four stacked vertical wedges, indicates a quadrilateral. Roughton and Canzoneri 1992, first drew attention to this group in the observational texts. Using reports 4–9, and 12 (none of which has a preserved distance "above" or "below"), they identified the front quartet as the compact albeit dim group of stars μ(13), 14, 15, and 16 Sagittarii, which is very slightly north of the ecliptic. Report 3, however, situates Mars "above" (i.e. north of) the front star of the quartet at a date when the planet's latitude was −1.7°; and report 10 locates Saturn, at latitude +1.72°, 3 cubits "above" the front quartet. The circumstance that report 3 specifies a particular star in the group might imply that the group had a significant longitudinal breadth. I suggest that the front quartet should be identified as γ^2, δ, ε, and η Sagittarius, the sidereal coordinates of which are as follows:

γ^2 Sgr: 246.6, −6.6 (magnitude 3.0)
δ Sgr: 249.9, −6.2 (magnitude 2.7)
ε Sgr: 250.4, −10.7 (magnitude 1.8)
η Sgr: 249.0, −13.0 (magnitude 3.1)

a9. 4-ÀM *ár šá* PA *šá ana* ZA
The four rear (stars) of Pabilsag which are similar to the sign ZA

[24] Only stars attested in reports from the late fifth century B.C. on will be discussed here.

[25] Huber 1958. The longitudes were determined according to the following assumptions: that "behind" and "in front" mean ecliptic east and west respectively, that the cubit comprised 24 fingers and was approximately equivalent to 2.3°, and that the reported location of the moon in an eclipse report was its position at the beginning of the eclipse. Except for the last, all these assumptions are discussed later in the present paper.

[26] In the Sachs catalogue, a11 and a12 are certainly present, a8 and a9 were probably present, and a10 was probably absent. None of their longitudes are preserved, and the surviving portion ends just where a13 could have been listed.

Table 3. Reports pertaining to a8 (the front four stars in Sagittarius)

report	text	year	event	longitude
1	SpTU 4.171 9′-10′	−574[1]	Station of Saturn 3 cubits <in front>[2]	248.4
2	SpTU 5.268 Rev. 28	−460[3]	Station of Jupiter 2 <cubits> behind	<243.0[4]
3	H61 (BM36751) Obv. I 22′	−384	Passage of Mars above front star	244.2[5]
4	H66 (BM35531) Rev. V 26′-27′	−329	Station of Jupiter, direction and distance lost	
5	Diary -281 B Obv. 12′	−281	Passage of moon 1/2 cubit (direction lost)	249.0±1.2
6	BM34455 (GYT) Obv. 28′	−192	Station of Mars 2 <cubits> behind	248.0
7	BM34034 (GYT) Obv. 3–4	−187	Station of Jupiter 1 cubit behind	246.9
8	BM35420 (GYT) Obv. 24	−162	Station of Saturn 1 cubit behind	247.7
9	BM35317 (GYT) Obv. 18′-19′	−145	Station of Mars 1 cubit behind	250.0
10	BM34053 (GYT) Obv. 30	−133	Station of Saturn 3 cubits above	247.3
11	Diary -119 C4′ and B_2 3′	−119	Lunar eclipse 2 cubits behind	246.5
12	BM41571 (LBAT 1289) Obv. 6	−104	Station of Jupiter[6]	>248.4

[1] Hunger 1999, 190–191.
[2] The restored direction is the only one consistent with the other reports.
[3] Date from John Steele (private communication).
[4] Perhaps the indication "behind" is an error for "in front".
[5] Restoring the date as Artaxerxes II 20 VI [1]2 rather than [2]2 as in the edition. The last digit is not certain.
[6] The text incorrectly reads "the four *rear* stars"; corrected by Roughton and Canzoneri.

(Table 4)

Mean longitude from reports 3, 4, 5, and 8: 259.6
Longitude according to RSW catalogue: 260
Estimated latitude from reports 2 and 3: −3.4

Roughton and Canzoneri 1992, first reported this group. Using reports 3, 6, 7, 8, and 9, they identify the rear quartet as ν^1, ν^2, ξ^1, and ξ^2 Sagittarii, which is again a compact but dim group of stars just north of the ecliptic. They allude to but do not use report 4 because of difficulties with dating BM35196, for which see Appendix 4; on the date when the text states that Venus was "balanced above the four rear stars" it was at latitude +0.5°, in a situation west but not at all north of the ν-ξ group. Reports 2 and (very probably) 3 situate Jupiter 1 2/3 cubits "above" the group at dates when the planet's latitude was respectively 0.4° and 0.5°, while report 2 also indicates that the group extended over a large enough longitudinal interval to justify singling out its rear star. I suggest that the rear quartet comprised σ, ϕ, ζ, and τ Sagittarii, a group that incidentally was known to Hipparchus as the Quadrilateral (Ptolemy, *Almagest* tr. Toomer, 323 and n. 20). The sidereal coordinates of these stars are as follows:

Table 4. Reports pertaining to a9 (the rear four stars in Sagittarius)

1	H4 (BM32234) Rev. IV 3′	−464	Lunar eclipse "in the area"	
2	H66 (BM35531) Obv. III 22′-23′	−341	Station of Jupiter 1 2/3 cubits above the rear star (name of group lost)	255.8
3	H66 (BM35531) Rev. V 23′-24′	−329	Station of Jupiter 1 2/3 cubits <above?>[1]	260.4
4	H53 (BM35196) Rev. II 14′-15′	−287[2]	Passage of Venus above	260.8
5	Diary -249 A Rev. 3′	−249	Station of Saturn 1 cubit behind (name of group lost)	256.8[3]
6	Diary -247 B Rev. 4′ BM34048 (GYT) Obv. 3–4 BM55560 (GYT) Obv. 2–3	−247	Station of Jupiter behind	<259.4
7	BM34603 (GYT) Obv. 1–2	−222	Station of Jupiter behind[4]	<259.0
8	BM34455 (GYT) Obv. 27′	−192	Station of Mars 1 1/2 cubits behind (name of group lost)	260.5
9	Diary -190 B Rev. 16′	−190	Station of Saturn behind	<259.9

[1] Restoring the direction as "above" yields a longitude more consistent with the other data than any other direction.
[2] For the date see Appendix 4.
[3] Perhaps the reading "1 cubit *behind*" is an error for "in front".
[4] The text incorrectly reads "the four *front* stars"; corrected by Roughton and Canzoneri.

Table 5. Reports pertaining to a10, a11, and a12

a10, 1	Diary -567 Rev. 10′	−566	Passage of Mars above[1]	
a10, 2	Diary -209 D Obv. 17′	−209	Station of Jupiter 2 cubits behind	304.0
a10, 3	Diary -122 D Obv. 10′	−122	Lunar eclipse 3 cubits behind	304.1
a11, 1	Diary -123 A Rev. 15	−123	Lunar eclipse "opposite" (*ana tar-sa*)	321.4
a12, 1	H60 (BM34750) Obv. I 4–5	−386	Station of Jupiter (direction and distance lost)	331.9± *dist*.
a12, 2	Diary -366 III B6	−366	Lunar eclipse (number lost) cubits behind	<336.2

[1]In this early report the star is named "the small star which is 3 1/2 cubits behind the goat-fish."

σ Sgr: 257.7, −3.2 (magnitude 2.0)
τ Sgr: 260.2, −4.7 (magnitude 3.3)
ζ Sgr: 258.9, −6.9 (magnitude 2.6)
ϕ Sgr: 255.4, −3.7 (magnitude 3.2)

a10. MÚL TUR *šá* 2 1/2 KÙŠ *ár* MÚL *ár šá* SUḪUR MÁŠ
The small star which is 2 1/2 cubits behind the rear star of the goat-fish

(Table 5)

Mean longitude from reports 2 and 3: 304.1
This star has been identified by Hunger as ι Aqr; there is no plausible alternative.[27] The star's sidereal coordinates are:

ι Aqr: 304.0, −1.9 (magnitude 4.3)

a11. *qup-pu* IGI *-ú šá* GU
The front basket of the great one

(Table 5)

Longitude from report 1: 321.4
Longitude from RSW catalogue: 324? (reading uncertain)

The identification of this star or group is uncertain; there are no especially bright stars in the region. Hunger and Pingree propose ϕ or χ Aquarii.[28] I would suggest that the "basket" was a group comprising some or all of the following stars:

φ Aqr: 321.4, −0.9 (magnitude 4.2)
χ Aqr: 322.4, −2.8 (magnitude 4.9)
ψ^1 Aqr: 322.4, −3.8 (magnitude 4.2)
ψ^2 Aqr: 322.0, −4.2 (magnitude 4.4)
ψ^3 Aqr: 322.1, −4.7 (magnitude 5.0)

a12. *qup-pu ár-ú šá* GU
The rear basket of the great one

(Table 5)

Longitude from RSW catalogue: 337.5

The identification of this star or group is also uncertain. Hunger and Pingree propose λ Psc (though also identifying this star as the "tails of the swallow"):

λ Psc: 332.0, 3.5 (magnitude 4.5)

Another possible group of stars at about the same longitude is:

29 Psc: 334.5, −2.9 (magnitude 5.1)
27 Psc: 333.6, −3.1 (magnitude 4.9)
33 Psc: 334.2, −5.8 (magnitude 4.6)
30 Psc: 333.3, −5.7 (magnitude 4.3)

(These stars are displayed as the "rear basket" in Fig. 2.) However, the longitude in the RSW catalogue would agree better with one or the other of the following:

ι Cet: 336.2, −10.0 (magnitude 3.5)
ω Psc: 337.9, +6.4 (magnitude 4.0)

a13. DUR SIM-MAḪ
The ribbon of the swallow

27 Sachs and Hunger 1989, 186 and 1996, 298.
28 Hunger and Pingree 1999, 273.

Table 6. Reports pertaining to a13 (the ribbon of the swallow)

1	Diary -567 Rev. 16′-17′	−566	Mercury in front with Venus	
2	Diary -567 Rev. 19′	−566	Venus and Mercury enter	
3	H8 (BM36879) Rev. I 10	−525	Lunar eclipse (direction and distance lost)	
4	H59 (BM36600) Rev. VII 12	−395	Station of Mars 3 cubits <in front>	354.6
5	H59 (BM36600) Rev. VII 14	−395	Passage of Mars 1/2 cubit <below?>	353.4
6	Diary -380 A 5′	−380	Passage of Mars 6 fingers in front, 8 fingers above or below the “bright star” in the ribbon	
7	H60 (BM34750) Obv. IV 22–23	−362	Station of Jupiter 1/2 cubit <below?>	352.1
8	H61 (BM36751) Obv. V 22′	−316	Station of Mars below (star name lost)	351.4
9	H69 (BM32590) Obv. I 4′-5′	−284	Station of Mars, located (direction and distance lost) relative to the “bright star” in the ribbon[1]	
10	H72 (BM36308) Obv. III 6′-7′	−279	Station of Jupiter below	351.1
11	Diary -237 Obv. 19′	−237	Station of Mars 1/2 cubit in front	355.8
12	BM132286 (GYT) Obv. 6′	−212	Station of Saturn (distance and direction lost)	
13	BM34658 (GYT) Obv. 1	−196	Station of Jupiter (distance and direction lost)	
14	H78 (BM45687) Rev. II 5′	−172	Station of Jupiter 3? 1/2 cubits <behind> (star name lost)[2]	352.3
15	Diary -77 B Obv. 20′	−77	Station of Jupiter 1/2 cubit in front (star name lost)	355.8

[1] The restoration of DUR SIM-MAḪ at Rev. II 20’ is probably incorrect, since the report fits η Psc.
[2] Some doubt applies to this report, since both the star name and the direction are lost.

(Table 6)

Mean longitude from reports 4, 5, 8, 10, 11, 14, and 15: 353.5
Longitude according to RSW catalogue: 356.25? (reading uncertain)
Estimated latitude from report 5: +0.8

In early reports (cf.), the “ribbon of the swallow” and “ribbon of the fish” (or “ribbon of Anunitu”) apparently refer to the two arcs of stars that in the Greco-Roman constellation Pisces form the lines of the fishes.[29] The “ribbon of the fish” was later narrowed down to the single Normal Star η Psc (c1). It does not seem that a single star came to stand regularly for the “ribbon of the swallow”. Hunger identifies the ribbon’s “characteristic star” as ε Psc (the brightest of the group), surely correctly;[30] but the rather wide

[29] Diary -567 Rev. 16′-20′, H55 (BM33066) right edge 3″-4″, and H56 (BM45674) C Rev. 3′.
[30] Hunger 2001, 210 and 220; note however that in Sachs and Hunger 1988, 85 and 88, Sachs and Hunger 1989, 89, and Hunger 2001, 34 and 289 the “ribbon of the swallow” is taken to be an alternate name for η Psc. In Diary -380 B Obv. 3’ and 11’ the broken references must be to η Psc.

spread of estimated longitudes derived from the reports, as well as the fact that only some reports specify the "bright star" of the ribbon, suggests that the ribbon comprised at least the stars δ Psc, ε Psc, ζ Psc:

δ Psc: 349.4, +2.2 (magnitude 4.4)
ε Psc: 352.9, +1.0 (magnitude 4.3)
ζ Psc: 355.1, −0.2 (magnitude 5.2)

The status of the six stars and star groups a8-a13 is puzzling. Most often they are cited in "positionals," i.e. as part of reports of stations and eclipses, but there are also a few passages: so few that it is clear that none of these stars were ever thought of as equivalent in status to the core 28 Normal Stars. There seem in fact to be no less than four categories of Normal Stars: first, the core 28, which were used regularly for observations of passages as well as positionals; secondly, alternates which were intermittently used for passages and positionals instead of one of the core 28, reflecting the fact that at an earlier period certain Normal Stars were actually star groups; thirdly, star groups (a8, a9, and a13) that were regularly used in positionals but almost never for passages; and fourthly star groups and stars (a10, a11, and a12) that were very seldom used at all.

Nevertheless, with the exception of a10, all the additional Normal Stars discussed above are included in the Sachs and RSW catalogues, whereas no other stars outside the reconstructed list appear in the preserved parts of the catalogues, which between them cover more than half the extent of the zodiac. The circumstance that some of the supplementary stars are actually groups of stars seems less strange when compared with the pattern of use of the Normal Stars belonging to the crab and the "head of the scorpion." But unlike those groups, the Sagittarius quartets and the "ribbon of the swallow" were only intermittently differentiated into their individual stars in observational records. On the whole, the two catalogues seem best to reflect the observational practice about the beginning of the fourth century B.C.

Figures 1 and 2 display the locations of the twenty-eight "core" stars and the thirteen other stars or star groups that are less frequently treated as Normal Stars (adopting the identifications presented above). It has often been remarked that the Normal Stars – meaning the reconstructed list of thirty-two stars and the antecedents of this list – are very unevenly distributed along the ecliptic, with, on the one hand, some very compact groupings, and on the other, two extensive gaps: not an arrangement well suited to tracking the progress of heavenly bodies along the zodiacal belt. Inclusion of stars a8-a13 helps to bridge the gaps. It is a mystery why these Normal Stars play such a limited role in the Babylonian observation records.

The remainder of this paper is concerned with characteristics of the planetary Normal Star observations that can most reliably be studied on the basis of relatively large counts of observations per Normal Star. For this reason, we will restrict our attention for the most part to the core 28 stars.

7. Orientation of "above" and "below"

The central question in the present paper will be, where was a planet in relation to a Normal Star when a Babylonian observer reported it to be, say, "2 cubits below" the star? There have been several past attempts to provide a partial or complete answer to this question, the most comprehensive being by G. Graßhoff.[31] Graßhoff concludes that the reported measurements of distance "above" and "below" a Normal Star (and also "north" and "south") are equivalent to difference in ecliptic latitude, and that distances "behind" and "in front of" (or "east" and "west" of) a star are equivalent respectively to positive and negative differences in ecliptic longitude. Without making an explicit assertion to this effect, he implies also that a report that does not give a distance east or west of a star can be interpreted as saying that the object was approximately at the same longitude as the star.[32] On the other hand, Neugebauer found that the direction from star to planet on the reported dates of passages varied erratically, in such a way as to "rule out any system of spherical coordinates in fixed relation to the ecliptic or the equator."[33]

Neugebauer's remarks were based on inspection of about one hundred observation reports. His criterion for verifying that the directional terms used in the reports represent sidereally fixed directions, for example an equatorial or ecliptic frame of reference, is that "the directions from a given star to any planet above or below it should always coincide." He cites two passage reports in both of which the directions from star to planet are significantly off ecliptic alignment (the direction in the second is still further from equatorial alignment), and generalizes from "this, and many similar cases." Graßhoff, with access to several hundred reports, argues towards an ecliptic frame of reference by way of a succession of progressively narrower hypotheses for the interpretation of the terminology. The confirmation or refutation of each hypothesis, however, is as anecdotal as Neugebauer's: a specific observation is chosen as an illustration, and appeal is made to "this and many more similar cases." In fact Graßhoff arrives at the best approximation to Babylonian observational practice that was possible within his framework of hypotheses, but it requires a more statistical approach to the reports to confirm this and to reconcile Graßhoff's conclusions with Neugebauer's.

A more refined description of the nature of the planetary passage reports can best be obtained by viewing an entire set of passages reported for a single star. Fig. 3 plots, in an ecliptical coordinate framework, the positions of the planets at sixty dates when they were reported as being specific (preserved) distances "above" or "below" a typical Normal Star close to the ecliptic, α Leo.[34] Consistently with Graßhoff's conclusion, the passages for which the planet is reported as "above" the star have the planet north of the star, and those for which the planet is reported as "below" have it south of the star. There is also some tendency for the planetary positions to cluster around the line of zero elongation, but there are also locations of planets in effectively all directions from the star, and eleven of them are more than a degree east or west of the star.

Figure 4 plots a slightly larger number (seventy-three) of passages of the same star, now including passages for which the distance is not preserved. In this figure passages

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[31] Graßhoff 1999.

[32] Graßhoff 1999, 139–141, commenting approvingly on Ptolemy's reduction of Normal Star reports.

[33] Neugebauer 1975, 546–547.

[34] In these and subsequent selections of data, I include reports that have a reported distance east or west, adjusting the computed longitudes by subtracting or adding 2.3° per cubit. Inclusion of these observations does not materially affect any of the conclusions.

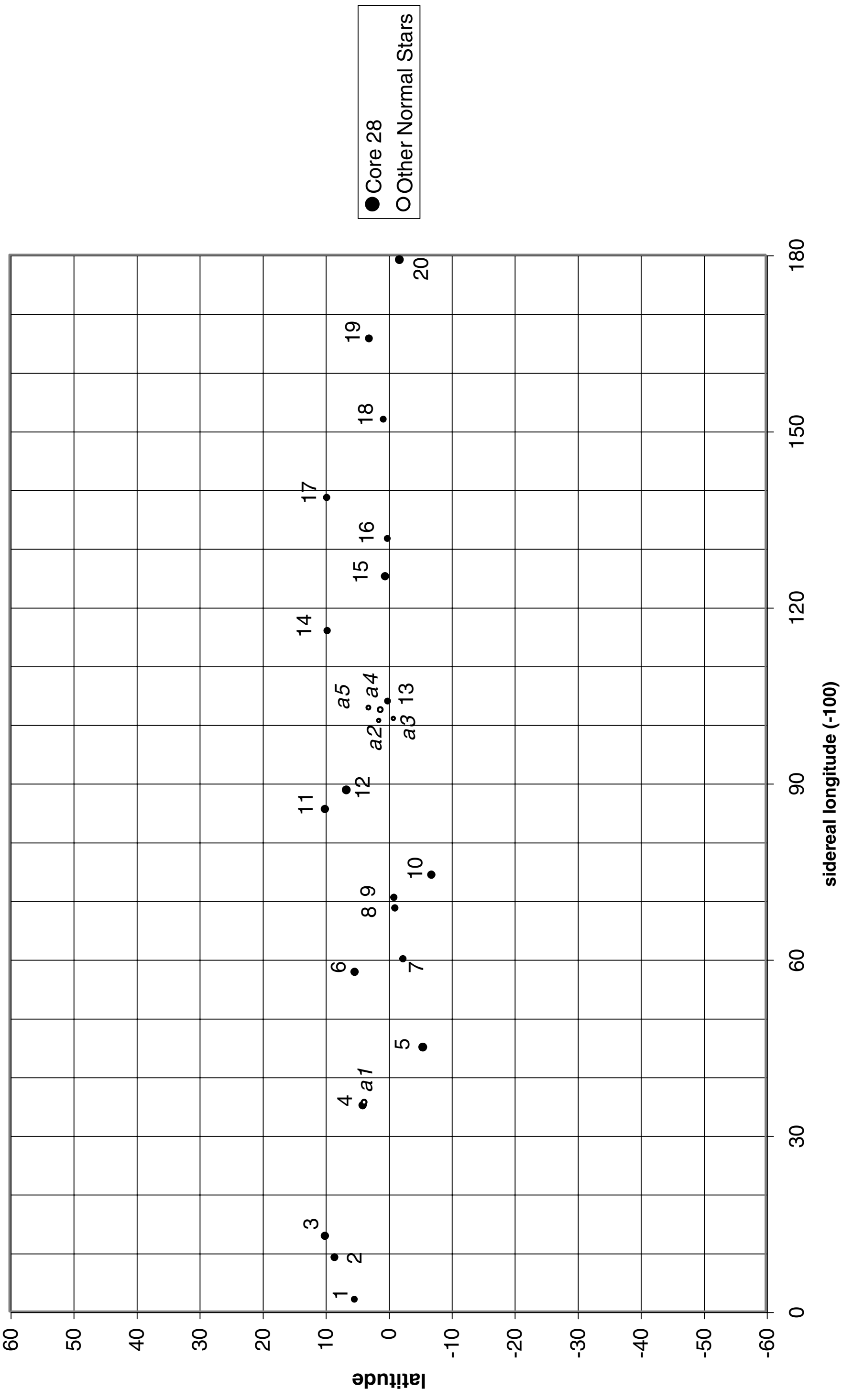

Fig. 1. Normal Stars (1)

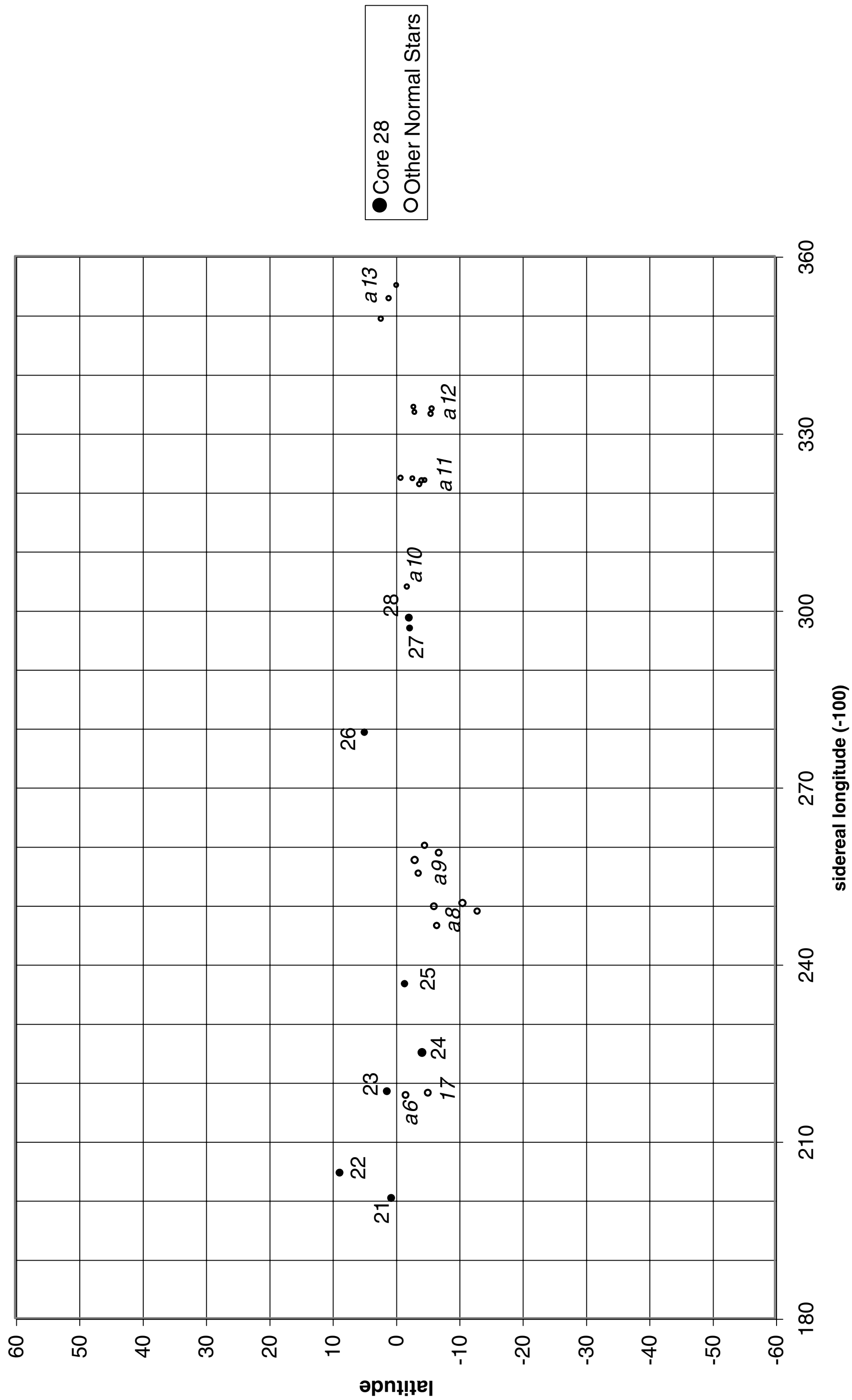

Fig. 2. Normal Stars (2)

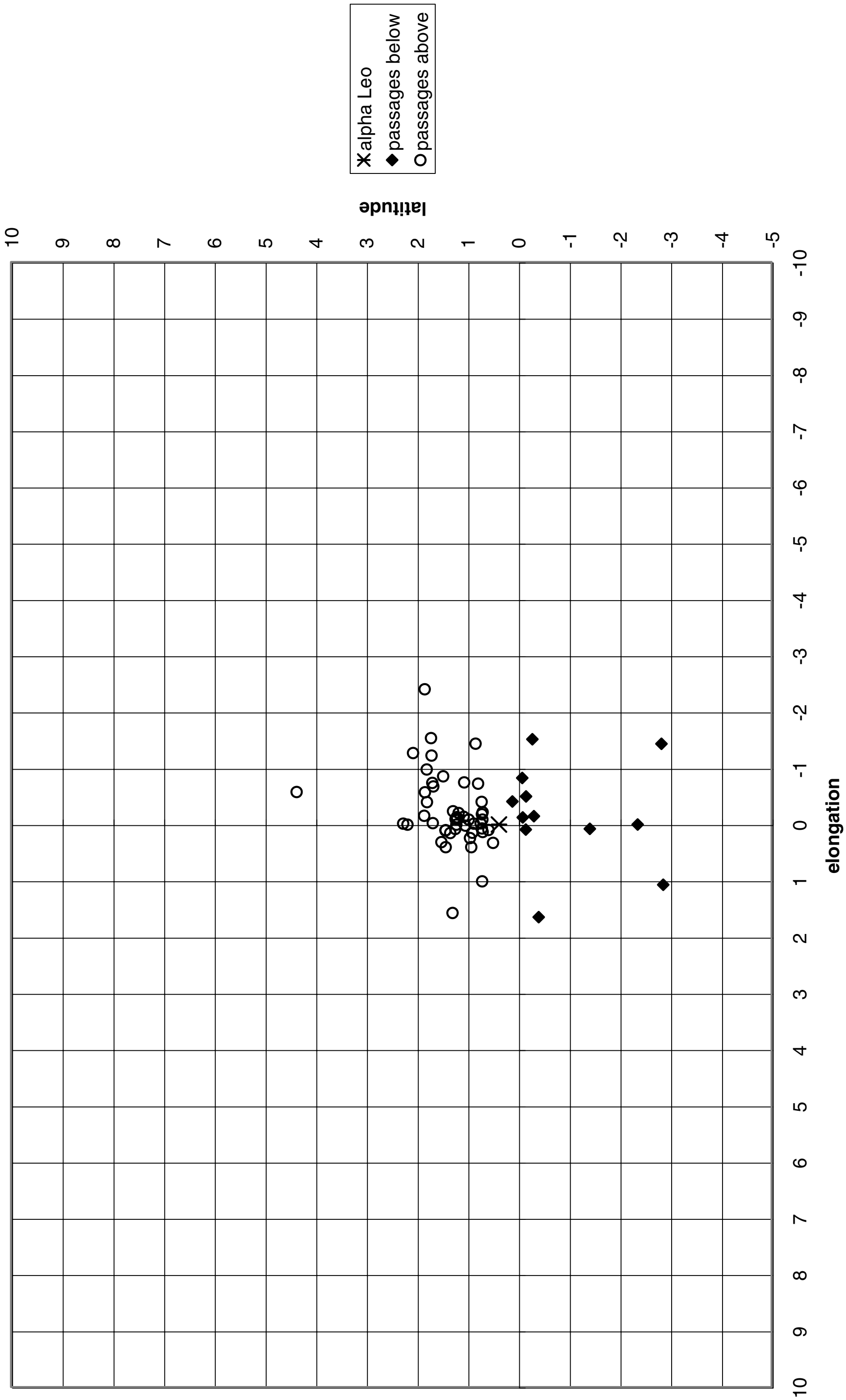

Fig. 3. Passages by alpha Leo

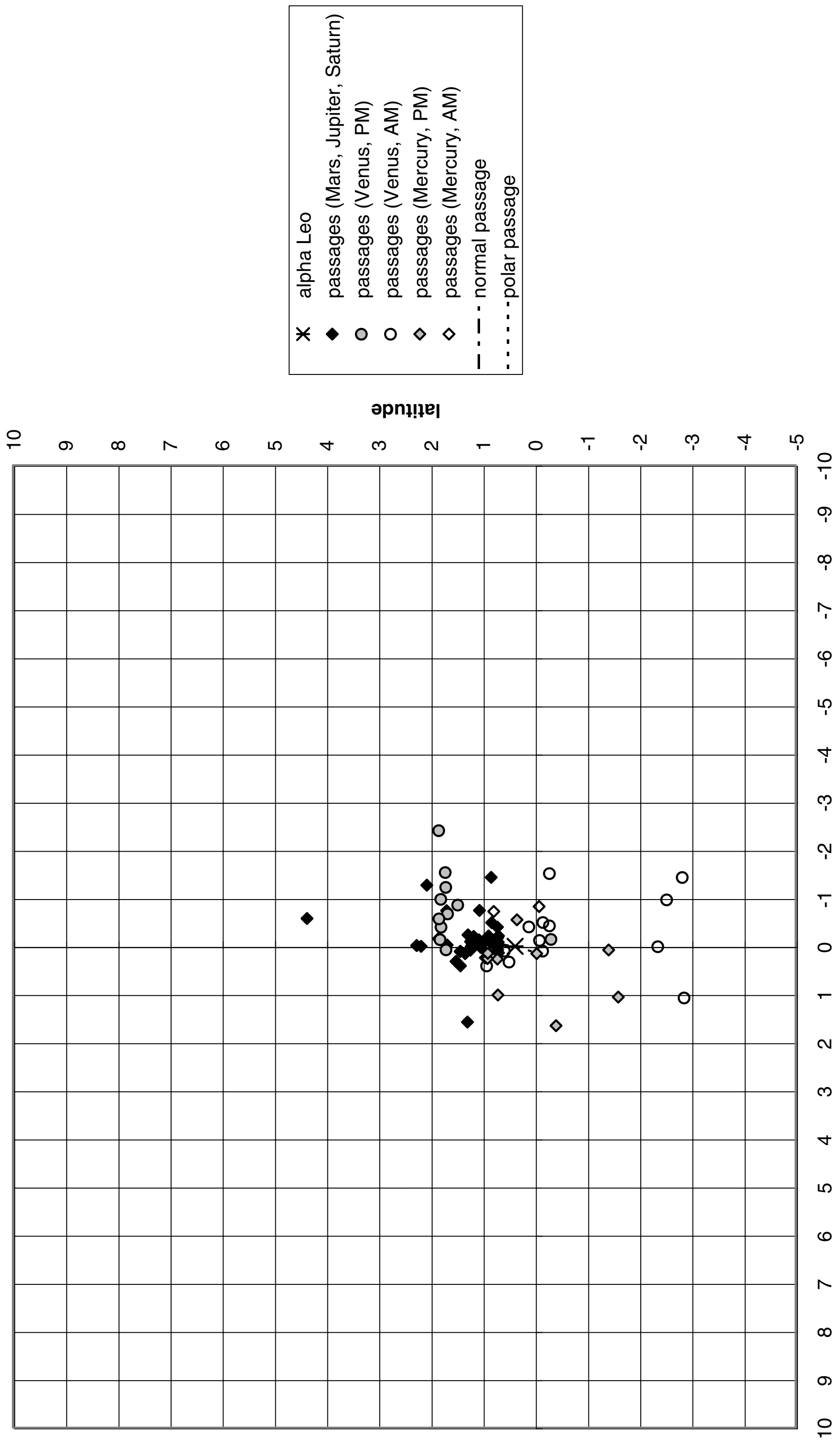

Fig. 4. Passages by alpha Leo

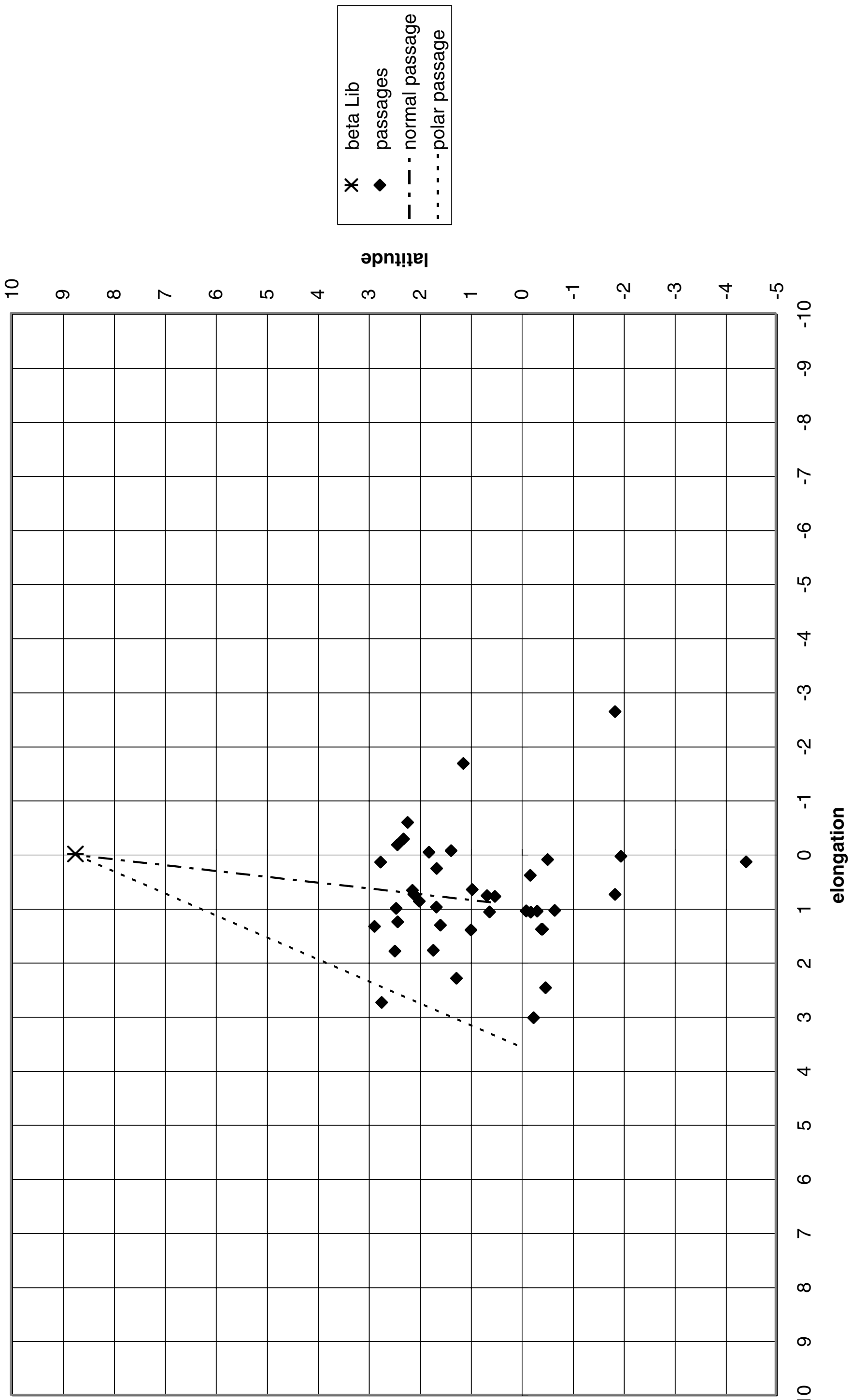

Fig. 5. Passages by beta Lib

Table 7. Median elongations of planets when stated to be "above" or "below" stars

planets	time of observation	number of passages	median elongation	standard error of median
Saturn	all	40	+0.21	0.23
Jupiter	all	204	−0.13	0.11
Mars	all	473	+0.14	0.09
Venus	all	620	−0.07	0.07
Mercury	all	190	−0.11	0.20
Venus	evening	331	−0.18	0.08
Mercury	evening	137	−0.28	0.22
Venus + Mercury	evening	468	−0.20	0.09
Venus	morning	289	+0.08	0.11
Mercury	morning	53	+0.25	0.41
Venus + Mercury	morning	342	+0.09	0.11
all planets	all	1527	−0.03	0.05

of Mercury and Venus are distinguished. It is evident that most of the cases where the planet is more than a degree from the star in longitude are passages of Venus or Mercury, which alone can progress more than one degree per day.

In Fig. 5 we have the incidence pattern of 41 passages of a typical Normal Star that is several degrees away from the ecliptic, β Lib (c22). Broken lines show (1) a line of alignment through the star that roughly bisects the cloud of planetary positions,[35] and (2) part of the hour circle through the star and the celestial poles. If passages were recorded when the planet was closest to the star's longitude, they ought to centre around the line of zero elongation, whereas if they were recorded when the planet was closest to the star's right ascension, they ought to centre around the hour circle. In this instance the bisecting line lies between the two, but is much closer to the line of zero elongation. There are eleven stars among the core 28 Normal Stars that are more than 5° from the ecliptic. Of these eleven, six have the line bisecting the passage positions on the *other* side of the line of zero elongation from the hour circle; two have the bisecting line between but closer to the hour circle; two have the bisecting line between but closer to the line of zero elongation; and two have the three lines too close for comparison to be significant. We will return to these alignment patterns in Sect. 8 below; for now it suffices to remark that longitudinal alignment is a reasonably good description of the criterion for a planetary passage, while equatorial alignment gives a much poorer fit.

More information can be derived from considering median elongations according to planet and time of observation (Table 7).[36] The fast planets show no significant tendency to have higher or lower elongations than the slow planets. If the passages were consistently recorded on the first night after (or the last night before) the crossing of

[35] The endpoint of this line is the "passage point" discussed in Sect. 8 below.

[36] Medians are preferable to means here because they are much less influenced by outliers. We are dealing here with data exhibiting a symmetrical and very roughly normal distribution, subject to a moderate rate of textual corruption.

some reference point or line, the recorded dates would be on average half a day later (or earlier) than the precise dates of crossing. On this hypothesis one would expect that the medians for Saturn and Jupiter would be about a half degree lower (or higher) than the medians for Venus and Mercury because Saturn and Jupiter progress very little in half a day while Venus and Mercury typically progress more than half a degree. The difference between the medians for morning and evening observations of Mercury and Venus is too small for there to have been any deliberate reference to the horizon in determining the date of passage, although it appears as if there was a slight tendency favouring more easterly sightings in the morning and more westerly in the evening.[37]

The distribution of positions relative to the Normal Stars shows that the Babylonian observers *usually* reported a passage of a planet on the night when it came nearest to having the same longitude as the star. Since observations were often possible only at one time of night, the closest observable position could be significantly east or west of the star, but the observers seldom chose to report this elongation. Only about one report in fifteen has a preserved statement that the planet was some number of fingers (or a fraction of a cubit) east or west of the star.[38]

8. Passage points and alignments for single stars

While we have confirmed that the frame of references for passages is essentially ecliptic, not equatorial, the direction from a star to where a planet was normally reported as passing the star turns out to vary significantly from star to star. We define the "passage point" for a Normal Star as the point whose elongation from the star is the median of the elongations of planets at reported passages, and whose latitude is the mean of the planets' latitudes at the passages.[39] Table 8 gives the pertinent information for the passage points of the core 28 Normal Stars. In the table, the longitude of each star is given as a Babylonian sidereal longitude according to Huber's estimate that Babylonian longitudes were 4° 28' greater than modern tropical longitudes in -100. "Polar elongation" is the elongation from the star of the point of the ecliptic having the same right ascension as the star, included in the table only to verify that passages are not aligned equatorially. The last columns give the mean absolute deviation of the elongations of passages with respect to the median and the estimated standard error of the median (assuming normal distribution). I have chosen not to project the passage points onto the ecliptic (i.e. giving the point of the ecliptic collinear with the passage point and the star) because the

[37] The differences between the morning and evening median elongations are too large to be accounted for by error in our assumption that observations took place on average four hours before or after midnight.

[38] Out of 1527 passages, 98 have a preserved east/west measurement. They are more common for the faster planets. The counts for the individual planets are Saturn: 1 out of 40, Jupiter: 3 out of 204, Mars: 21 out of 473, Venus: 53 out of 620, Mercury: 20 out of 190.

[39] As before, median is preferable to mean for the elongations because the median is much less influenced by outliers. Since, unlike the longitudes, the latitudes are not even nearly normally distributed, but are not subject to outliers, the mean is used for this coordinate. The periodic variation of the mean passage latitudes over the ecliptic, evident in Table 8, is a consequence of the aggregate patterns of latitudinal motion of the planets.

Table 8. Passage data for the core 28 Normal Stars

Normal Star		Coordinates in −100 (Babylonian norm)		Polar elong.	Number of passages	Passage point		Mean abs. deviation	Est. std. error
No.	Name	Longitude	Latitude			Elongation	Latitude		
c1	η Psc	2.09	5.26	−2.29	39	0.80	−0.75	1.25	0.40
c2	β Ari	9.24	8.41	−3.70	39	0.16	−0.19	1.28	0.34
c3	α Ari	12.89	9.91	−4.37	44	0.61	−0.34	1.23	0.34
c4	Pleiades	35.26	3.84	−1.61	46	−1.40	0.51	1.01	0.25
c5	α Tau	45.03	−5.61	1.85	45	0.58	0.49	1.28	0.34
c6	β Tau	57.84	5.21	−1.39	68	−0.94	0.47	1.01	0.22
c7	ζ Tau	60.05	−2.46	0.63	56	0.25	0.21	0.82	0.20
c8	η Gem	68.74	−1.16	0.21	60	−0.31	0.70	0.69	0.15
c9	μ Gem	70.53	−1.04	0.21	70	−0.12	0.58	0.81	0.18
c10	γ Gem	74.38	−6.98	1.03	62	−0.27	0.64	1.11	0.24
c11	α Gem	85.60	9.94	−0.74	57	−1.36	0.81	0.95	0.22
c12	β Gem	88.83	6.52	−0.27	67	0.17	1.11	0.95	0.20
c13	δ Cnc	103.96	−0.01	0.02	44	−0.23	0.87	0.50	0.14
c14	ε Leo	115.96	9.55	1.69	53	−0.17	1.01	1.21	0.38
c15	α Leo	125.23	0.37	0.11	73	−0.10	0.78	0.45	0.10
c16	ϱ Leo	131.66	0.04	0.03	57	−0.08	1.07	0.52	0.12
c17	θ Leo	138.66	9.65	3.17	46	3.34	1.36	1.51	0.39
c18	β Vir	151.97	0.65	0.27	57	−0.09	1.08	0.60	0.18
c19	γ Vir	165.74	2.95	1.23	59	0.13	0.87	0.50	0.12
c20	α Vir	179.13	−1.92	−0.81	66	−0.22	0.76	0.73	0.16
c21	α Lib	200.36	0.62	0.28	53	−0.08	1.07	0.69	0.20
c22	β Lib	204.66	8.73	3.57	41	0.88	0.63	0.80	0.22
c23	β Sco	218.47	1.27	0.48	40	−0.13	1.27	0.77	0.42
c24	α Sco	225.04	−4.29	−1.44	48	0.57	0.40	0.90	0.21
c25	θ Oph	236.67	−1.55	−0.40	54	0.43	0.07	1.24	0.28
c26	β Cap	279.30	4.82	−0.15	49	1.09	−0.77	0.84	0.19
c27	γ Cap	296.95	−2.34	0.42	46	−0.16	−0.89	0.66	0.19
c29	δ Cap	298.71	−2.22	0.43	42	0.20	−1.14	0.67	0.18

elongations of such projected points are meaningless when the star's latitude is small, and not appreciably different from the elongations of the passage points when the star's latitude is large.

The most striking fact revealed by this table is that a large number of Normal Stars have passage points whose elongations are significantly far from zero. The stars in question all have comparatively large latitudes, and the directions from the stars to the passage points deviate from ecliptic north-south following no regular pattern. Reports from the earliest and latest periods are affected by the deviations, as can be seen from the examples in Table 9, among which only θ Leo shows a significant change in deviation between early and late observations.

The deviations are an important clue to the method by which passages were observed. They cannot be explained as products of a consistent frame of reference different from the ecliptic, or systematic errors due to a particular instrument used for the measure-

Table 9. Normal Stars having passage points with large elongations

star	median elong. ($y < -200$)	passages	est. std. error	median elong. ($-200 \leq y$)		est. std. error
η Psc	0.79	17	0.51	0.86	22	0.60
Pleiades	−1.31	29	0.37	−1.43	17	0.27
β Tau	−1.00	37	0.29	−0.89	31	0.35
α Gem	−1.36	25	0.34	−1.34	32	0.28
θ Leo	3.91	27	0.63	2.56	19	0.25
β Lib	1.06	17	0.40	0.74	24	0.26
β Cap	1.05	25	0.27	1.13	24	0.27

ments. The only credible reason that the directions from particular Normal Stars to their passage points should exhibit consistent deviations with no overall pattern is that the directions were determined according to established rules by reference to other stars. The rules must have been devised by the end of the fifth century B.C., and they were transmitted through generations of observers as long as the Diaries were being compiled.

We can only conjecture what rules were employed for specific stars. The simplest rule would be to prescribe an alignment through the Normal Star and a second nearby bright star. Thus the two most pronounced deviations, considered as angles from due ecliptic north-south, belong to θ Leo and the Pleiades, and for both one can find nearby bright stars such that the passage points are close to the great circle through the Normal Star and the second star (Figs. 6–7):

star	longitude (−100)	latitude (−100)
θ Leo	134.22	9.65
δ Leo	131.97	14.28

elongation of collinear point at latitude of passage point: 3.89
elongation of passage point: 3.17
elongation of passage point (observations before −200): 3.91
elongation of passage point (observations after −200): 2.56
(There is no obvious bright star to account for the later alignment.)

star	longitude (−100)	latitude (−100)
Pleiades (midpoint)	30.70	3.84
ζ Per	33.97	11.09

elongation of collinear point at latitude of passage point: −1.53
elongation of passage point: −1.40

Some further examples of plausible alignments follow (Figs. 8–13):

star	longitude (−100)	latitude (−100)
η Psc	357.65	5.26
o Psc	358.52	−1.76

elongation of collinear point at latitude of passage point: 0.74
elongation of passage point: 0.80

star	longitude (−100)	latitude (−100)
β Ari	4.80	8.41
ξ Cet	4.87	−4.42

elongation of collinear point at latitude of passage point: 0.04
elongation of passage point: −0.19

star	longitude (−100)	latitude (−100)
α Gem	81.05	9.84
δ Gem	79.36	−0.44

elongation of collinear point at latitude of passage point: −1.49
elongation of passage point: −1.36

star	longitude (−100)	latitude (−100)
β Gem	84.39	6.52
κ Gem	84.49	2.86

elongation of collinear point at latitude of passage point: 0.16
elongation of passage point: 0.17

star	longitude (−100)	latitude (−100)
β Lib	200.22	8.73
σ Lib	201.57	−7.39

elongation of collinear point at latitude of passage point: 0.68
elongation of passage point: 0.88

star	longitude (−100)	latitude (−100)
β Cap	274.86	4.82
π Cap	275.54	1.14

elongation of collinear point at latitude of passage point: 1.03
elongation of passage point: 1.09

As the cases of β Ari and β Gem illustrate, alignments of pairs of stars can also account for passage points that fall close to the expected location, due north or south of the Normal Star with respect to the ecliptic. On the other hand there are stars, for

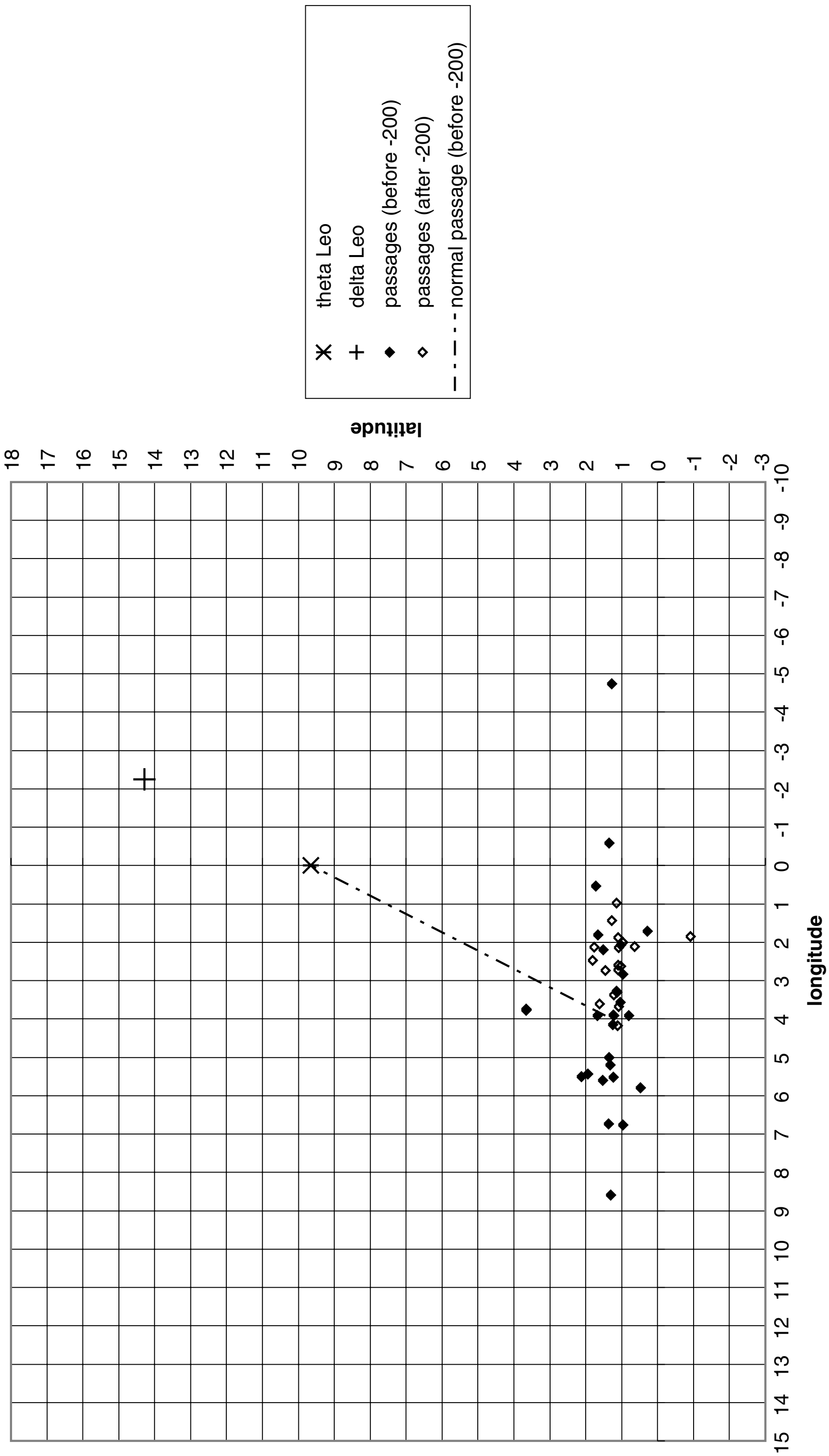

Fig. 6. Passages of theta Leo

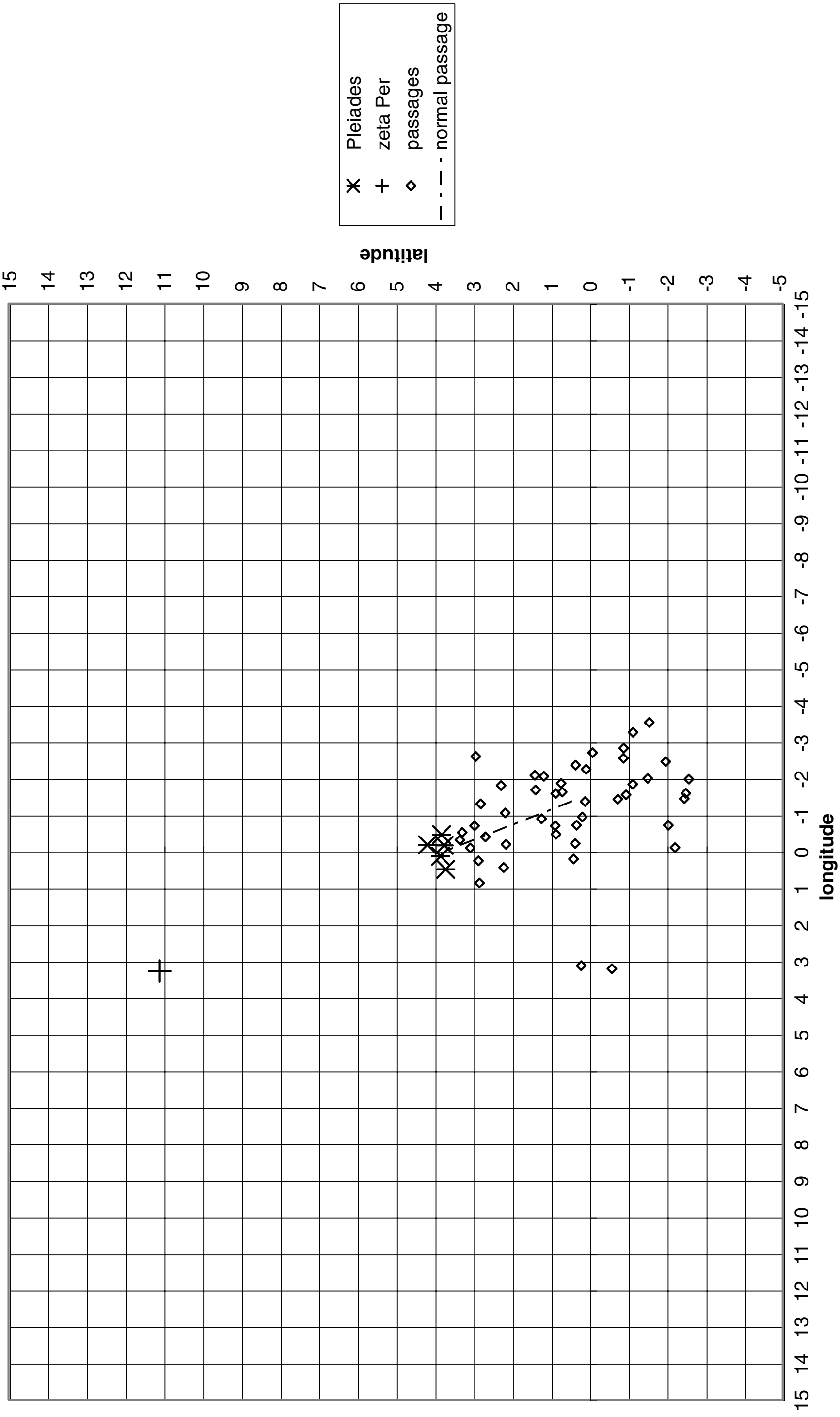

Fig. 7. Passages of the Pleiades

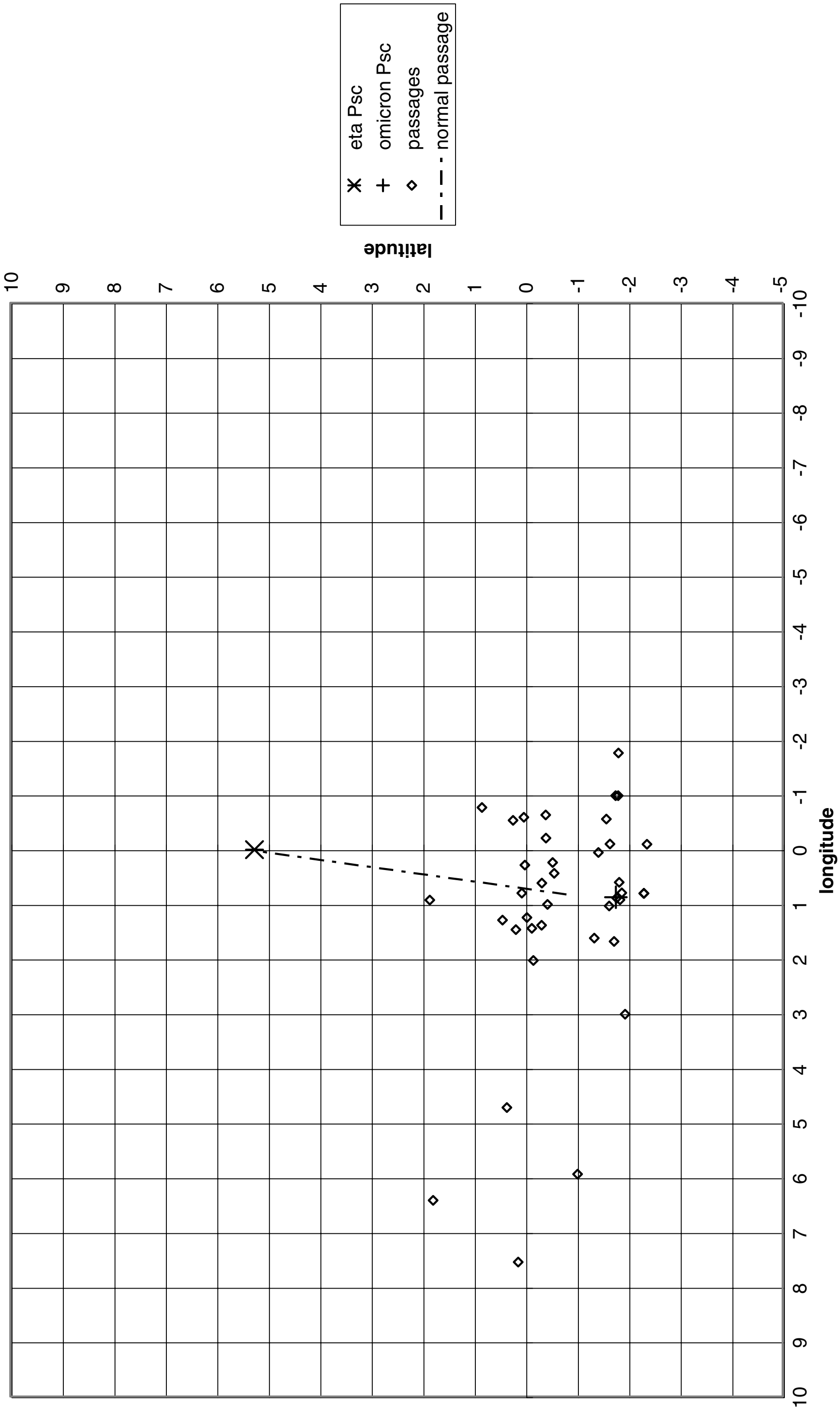

Fig. 8. Passages of eta Psc

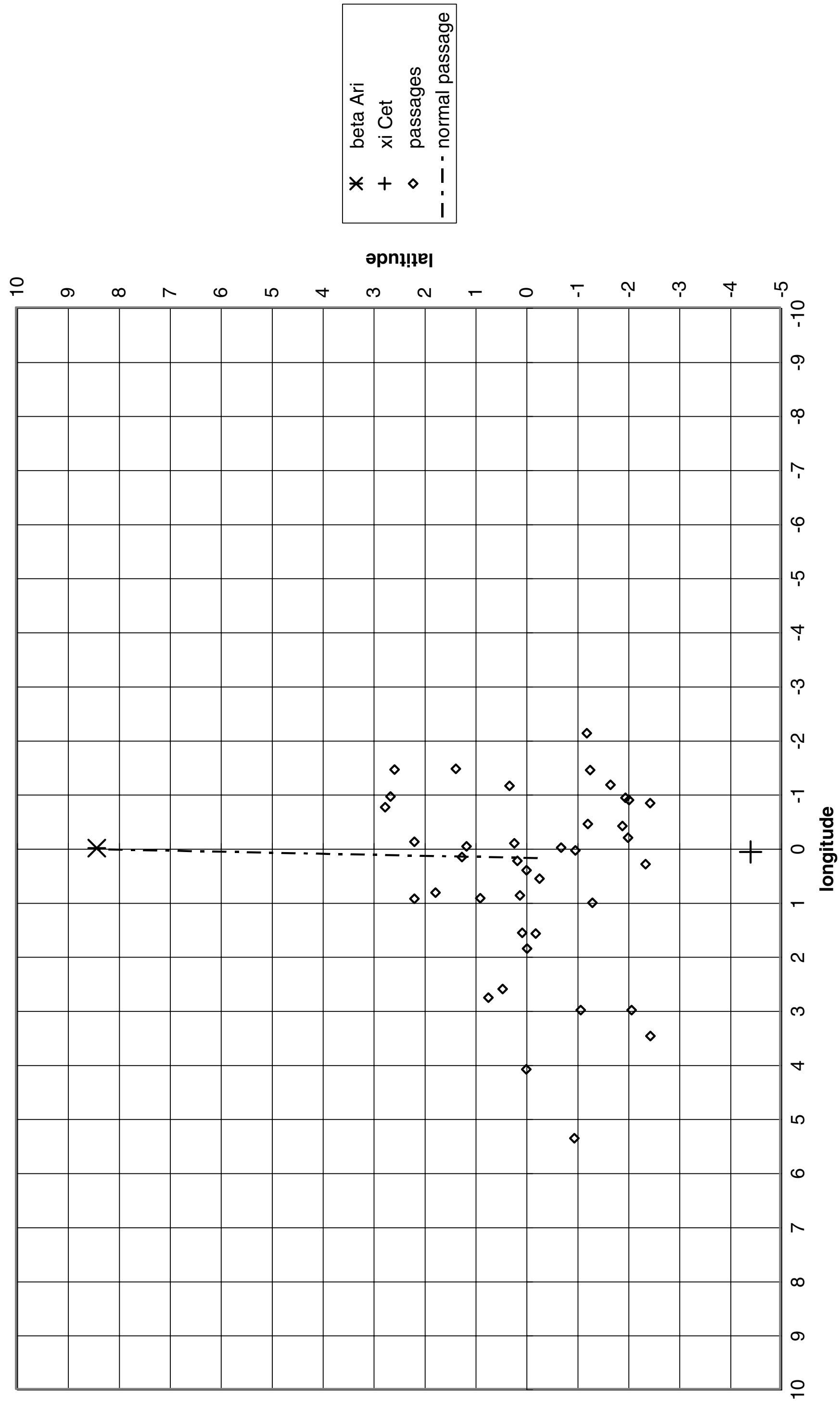

Fig. 9. Passages of beta Ari

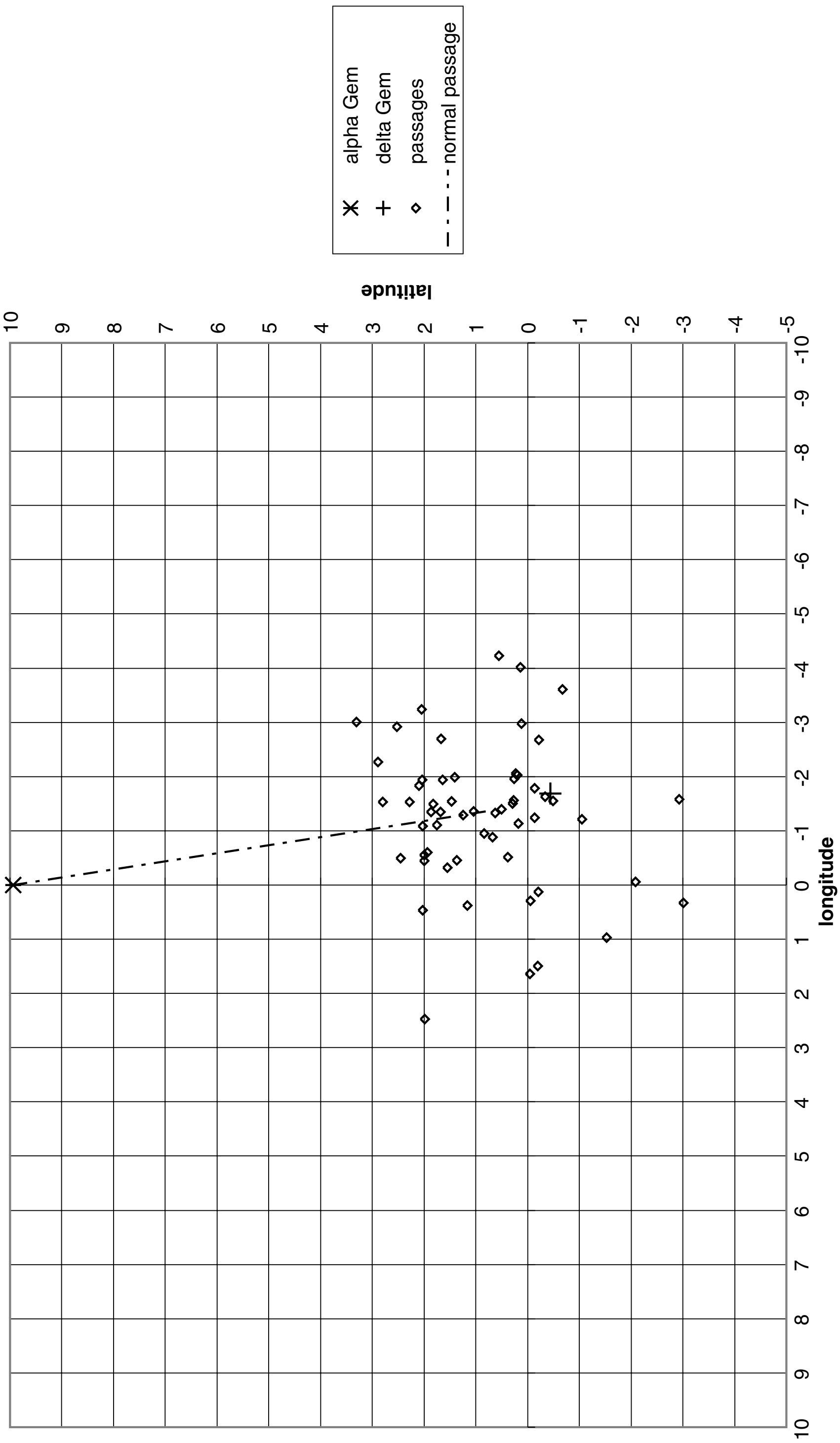

Fig. 10. Passages of alpha Gem

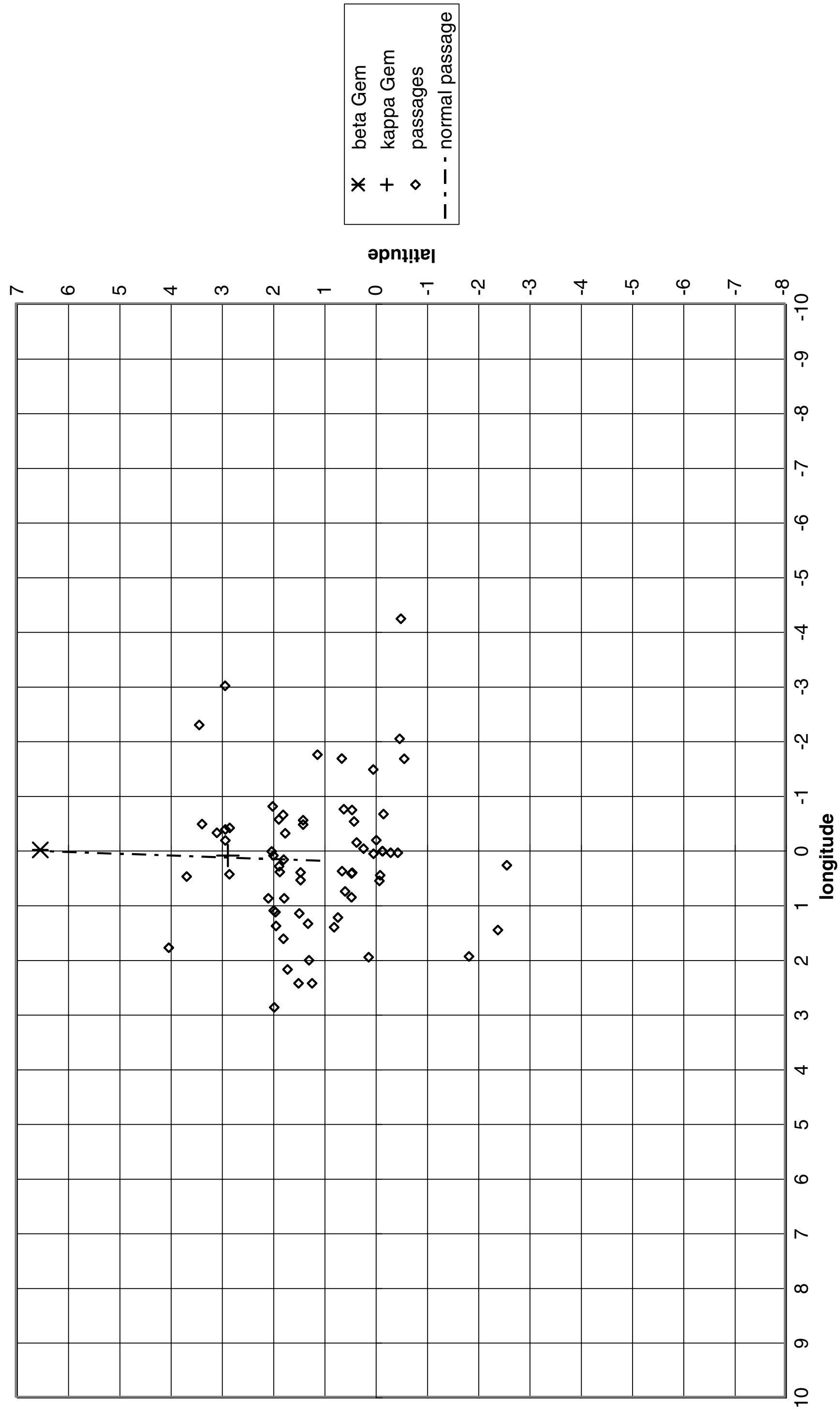

Fig. 11. Passages of beta Gem

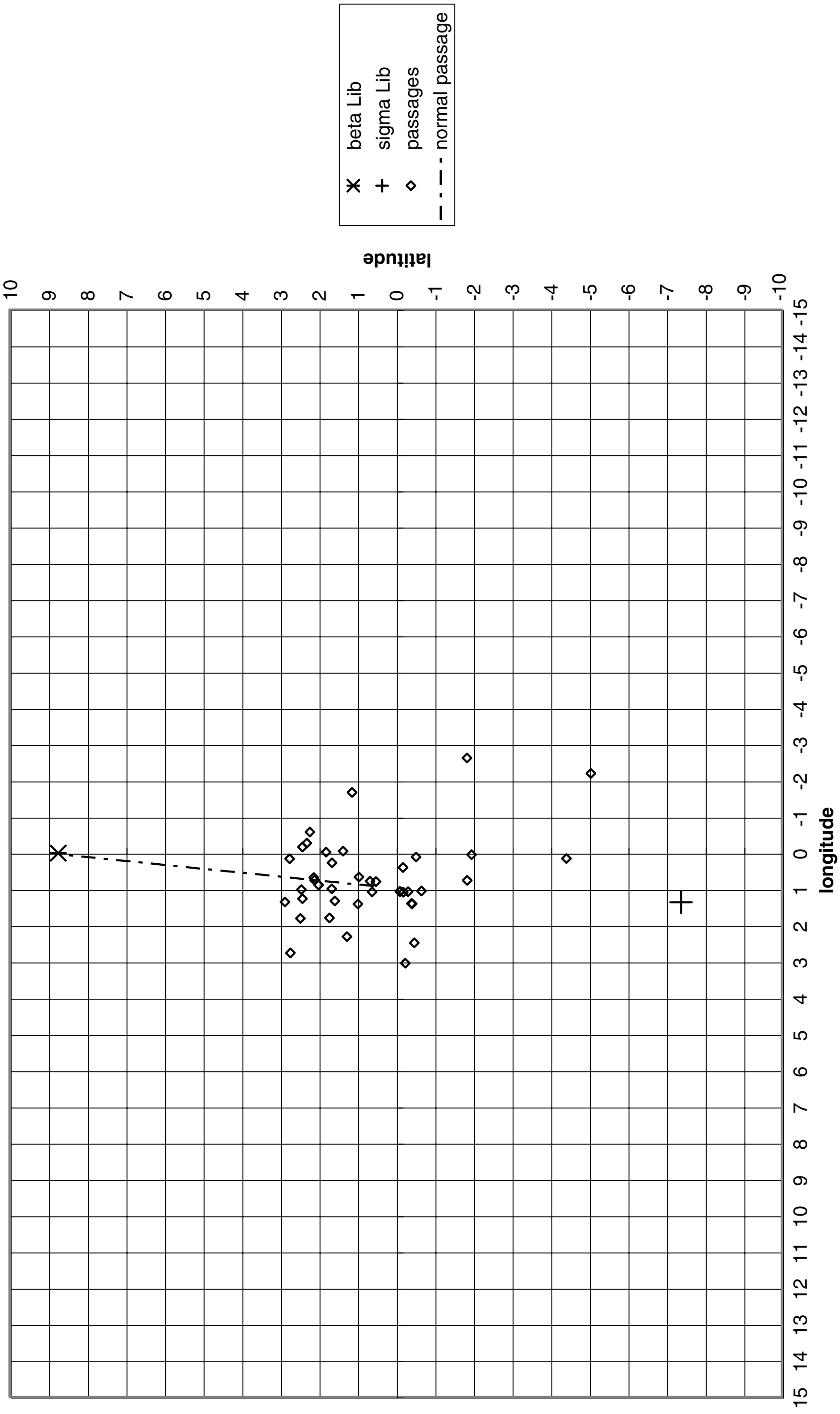

Fig. 12. Passages of beta Lib

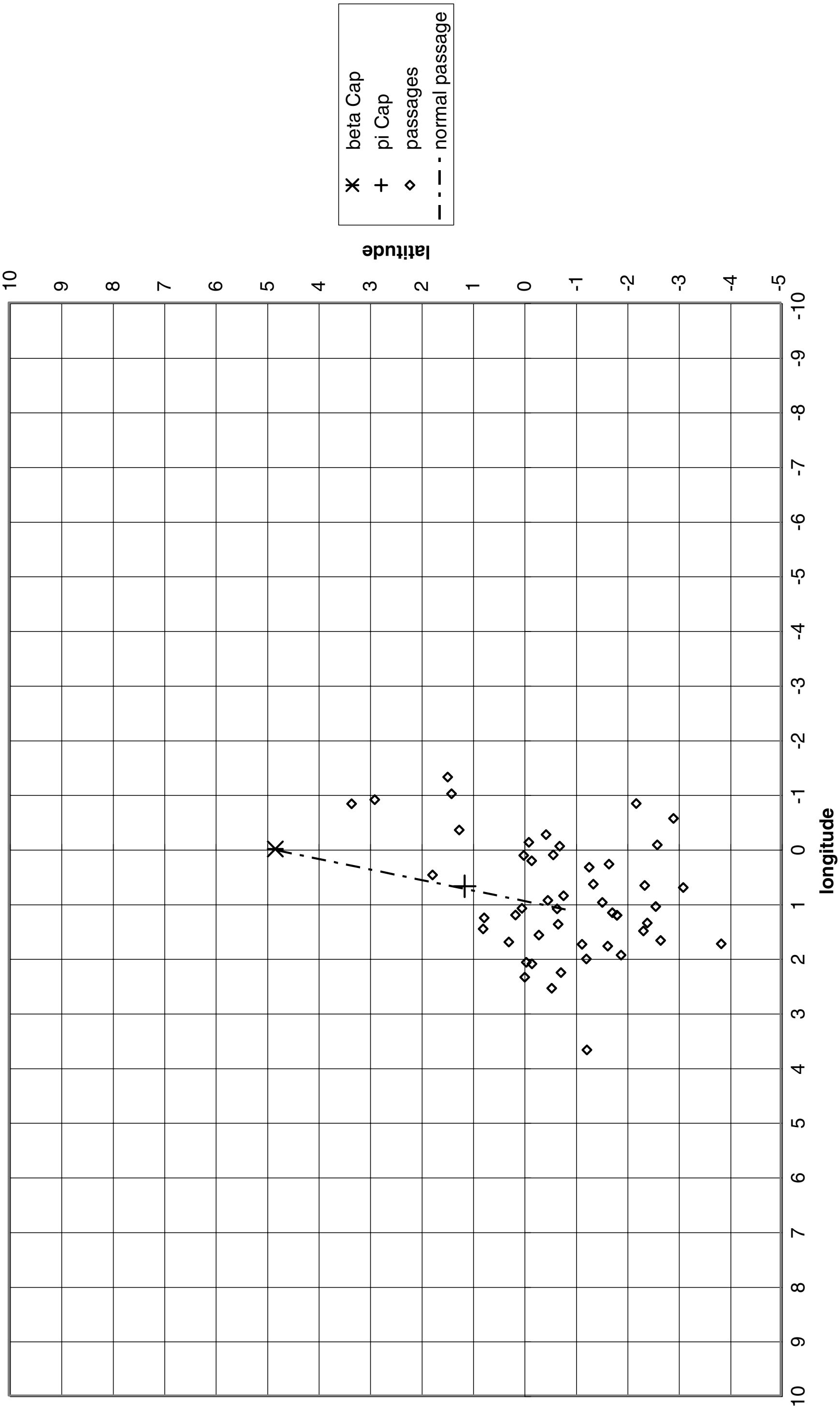

Fig. 13. Passages of beta Cap

example α Tau and β Tau (and θ Leo for the later observations), for which no suitable bright star gives the desired alignment. Hence there must have been more complicated rules, say using a line through the Normal Star and passing a certain number of fingers east or west of another star.

How were the observations made? I would guess that if they were not simply done by the unaided eye, a graduated ruler, or still better, a taut string or thread with graduated markings was held at a more or less fixed distance from the eye. An explicit, if unfortunately obscure, reference to observing with a taut string occurs in an important collection of astronomical and astrological procedure texts, TU 11, Obv. 18.[40]

It would be interesting to know how aware the Babylonian observers were of the fact that there was so much variation in the sighting directions associated with the Normal Stars. The preserved longitudes in the Sachs and RSW catalogues fail to clarify this question. In the RSW catalogue, four longitudes of securely identified core 28 stars, expressed to a precision of a large fraction of a degree, can be read. All four longitudes are between 1.2° and 2.2° higher than the actual sidereal longitudes (using Huber's norm), with a mean difference of 1.6°. If we compare instead with the longitudes of the passage points, the mean difference diminishes to 1.1°, but the range of variation in the differences increases, from 0.4° to 1.7°. (Two of the stars in question, β Cap and η Psc, have significantly divergent passage points.) In the Sachs catalogue, four longitudes of core 28 stars, expressed to a precision of one degree, can be read, in addition to a fifth (β Vir) for which the text gives two variant longitudes one degree apart. With the exception of θ Leo, the longitudes according to the catalogue are all within one degree of the actual sidereal longitudes (adopting the higher variant for β Vir), with the differences ranging from −1.0° to +0.3° and a mean difference of −0.4°. Comparison with the longitudes of the passage points results in a smaller range, from −0.9° to −0.3°, with a mean difference now of −0.6°. (Only β Lib among these stars has a significantly divergent passage point.) Nothing definite can be inferred from these comparisons. However, the Sachs catalogue's longitude for θ Leo is a full 3.3° greater than this star's actual sidereal longitude, a difference that surely reflects the exceptionally large divergence between the passage point and the star's longitude. For this star, at least, the catalogue's longitude evidently represents the expected longitude of a heavenly body observed as passing the star.

9. Cubits and fingers

Most passage reports give only a single distance, above or below the star, and it is not easy to see from consideration of individual reports whether the distance is measured radially from the star to the planet, or, like a coordinate, from the star in a fixed direction that would presumably be the same as the direction of the passage alignment discussed in the preceding section.[41] By considering the collective behavior of the reports, we

[40] Brack-Bernsen and Hunger 2002, 19 and 79–80 (with references to other "strings" in Babylonian texts on stars).

[41] Graßhoff 1999 129–133, reasons by a different route. He first refutes the hypothesis that *in front* and *behind* distances are radial, adducing a single report as a counterexample and stating that it is "by far not a singular case." Considering coordinates to be the only alternative, he estab-

can eliminate the first possibility. If the reported distances were radial, then the set of all actual positions of the planet relative to the Normal Star on dates when a passage with a given distance is reported ought to approximate a circle, but in fact the relative positions tend to cluster around lines of constant relative latitude (Fig. 14). It is therefore legitimate to interpret reported distances as latitudinal differences for the purpose of estimating the degree equivalent of the cubit and finger. In the following estimates, we remove from the data collection the passages of the Pleiades, because we do not know what point of this cluster one should measure from, and the passages of θ Leo because, as we have seen, the direction of alignment for this star was quite far from the line of equal longitude.

It will be helpful to settle at the outset the related questions of whether there were two sizes of cubit and how many fingers made up one astrometrical cubit. Kugler used just three texts of Normal Star passages to estimate the degree value of the cubit, and found that some passage reports in each text yielded a value close to 2°, while others yielded a value close to 2.5°.[42] Moreover, from a single pair of reports for different dates when Jupiter was passing γ Gem at nearly the same latitude, one report giving a distance of 2 2/3 cubits and the other a distance of 2 cubits 20 fingers, he inferred that 20 fingers was the equivalent of 2/3 cubit, hence that the cubit in these reports comprised 30 fingers. Since these were also reports from which he obtained a 2.5° cubit, the finger appeared to be equivalent to 5′. As for the 2° cubit, Kugler remarked that in the reports in his texts where a cubit of this size was employed with additional fingers, the number of fingers was always 4 or 8, i.e. a simple fraction of 24 but not of 30; hence he concluded that the finger was invariably 5′, while the cubit could be either 2° (24 fingers) or 2.5° (30 fingers), reflecting the well-established fact that the ordinary cubit of linear measurement had comprised 30 fingers in the Old Babylonian period, whereas a 24-finger cubit had come into use by the Late Babylonian period.

Kugler's assertion that astrometrical cubits of 30 as well as 24 fingers existed has been often repeated, notwithstanding the *prima facie* implausibility of the notion that the Babylonian observers had two different cubit units, which for several centuries they used concurrently and without making any indication of which cubit was employed in any particular measurement. In fact Kugler's evidence for the two cubits is a statistical fluke that vanishes as soon as one takes into consideration a reasonably large number of observation reports. In Fig. 15 the distribution of values obtained by dividing the latitudinal difference in degrees by the reported distance in cubits is shown for the 653 reports that give a distance expressed purely in cubits. The pattern does not display separate peaks corresponding to a 2° and 2.5° cubit.[43]

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lishes through selected examples that longitudinal difference appears to be a good interpretation of distance in front/behind, and latitudinal difference of distance above/below.

[42] Kugler 1910 547–550.

[43] Graßhoff's graphs on p. 138 show a similar distribution, though with less smoothness because of the smaller data set and because he separates "above" from "below" reports. Yet he retains the hypothesis of two distinct cubits (p. 137), ostensibly because "the distribution of values is not Gaussian."

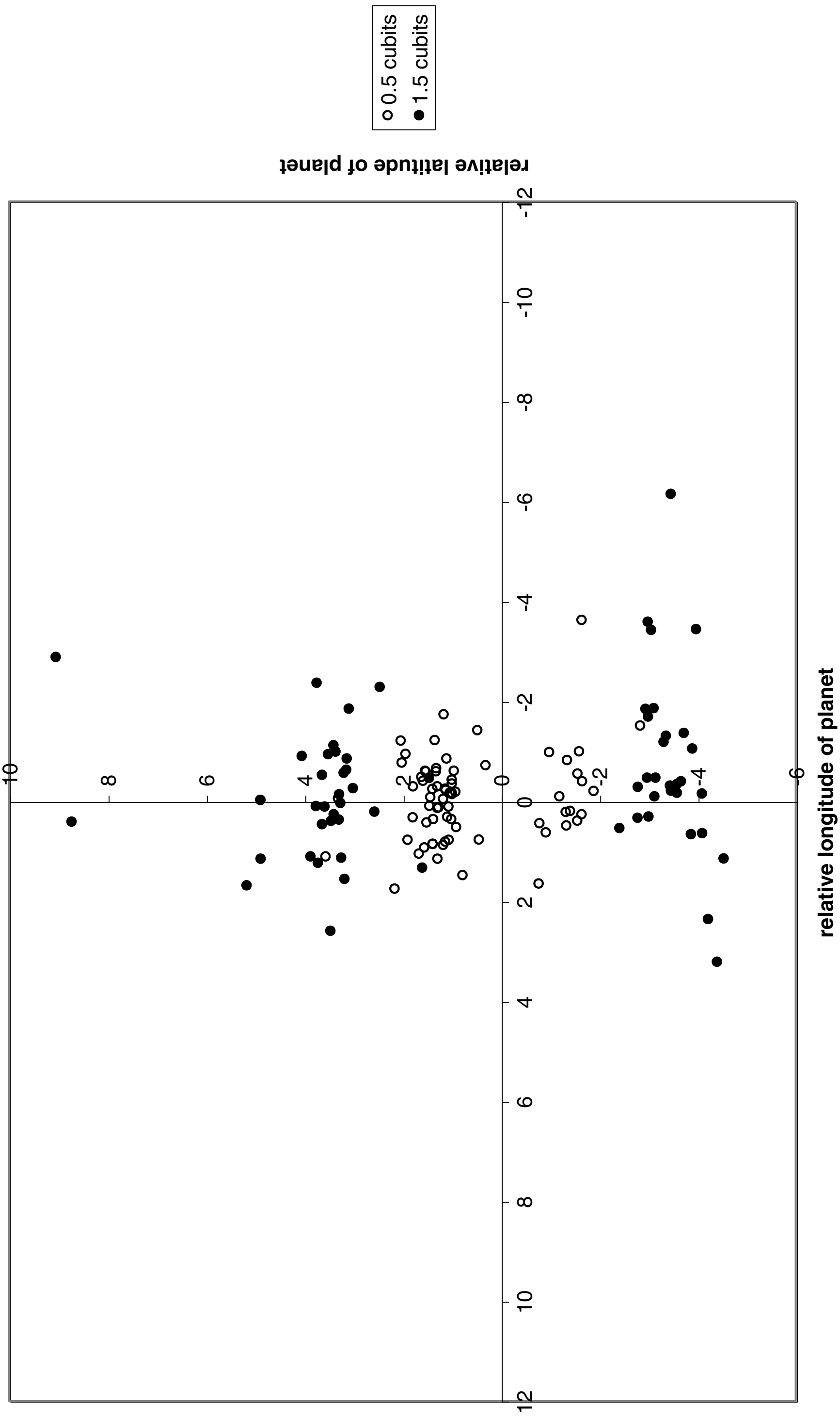

Fig. 14. Position of planet relative to Normal Star for fixed distance above/below

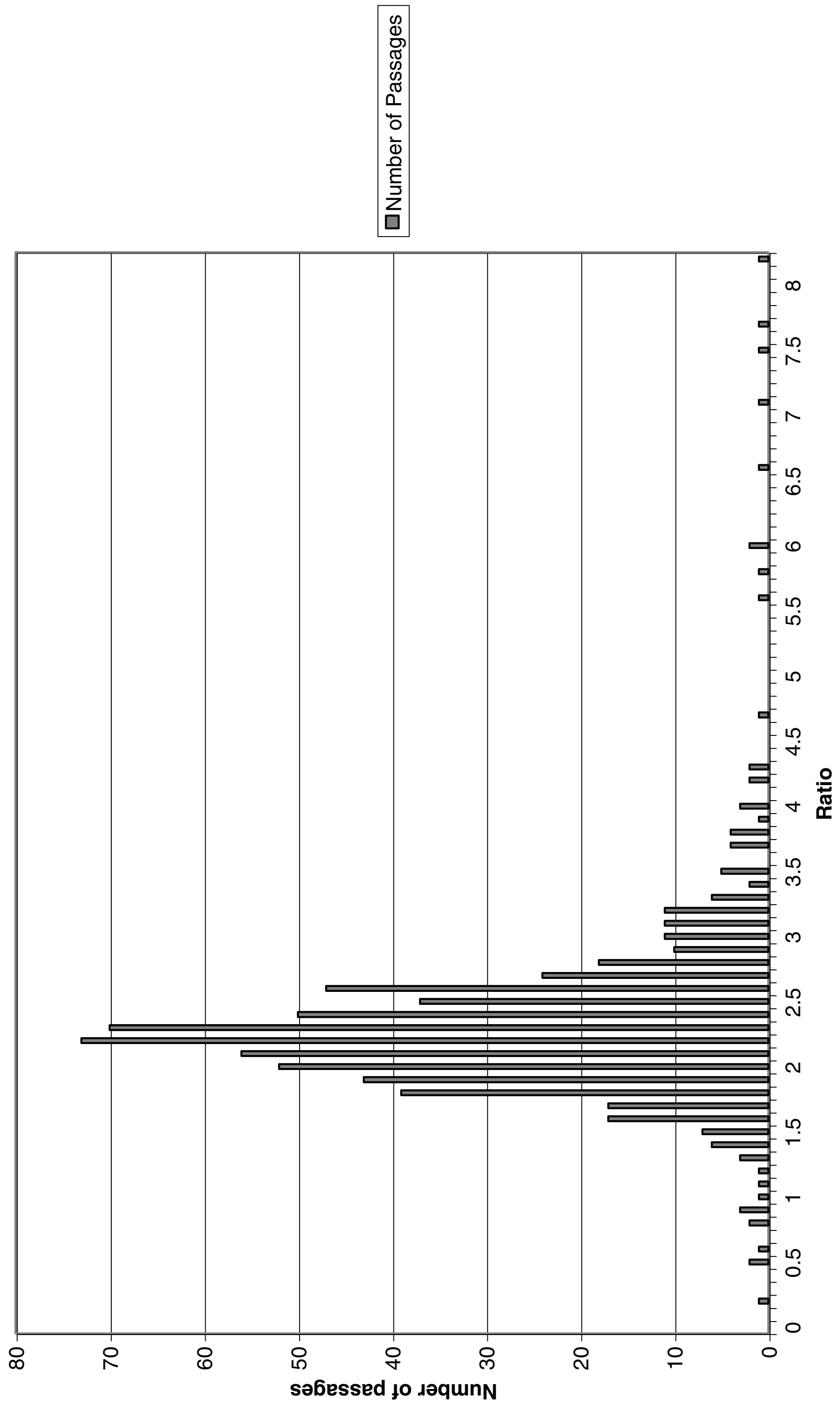

Fig. 15. Distribution of cubit-to-degree rations

The equivalence of 1 cubit with 24 fingers can be established by two empirical tests. Steele has pointed out that the attested distance measurements expressed in fingers in passage reports, combined with attested distances in fractions of cubits, lead to a plausible and even gradation of values if the cubit consisted of 24 fingers, but not if it consisted of 30 fingers.[44] Moreover one can estimate the effective degree equivalent of the cubit and finger separately by comparing the passage reports with modern theory. Since, as we shall see, the degree equivalent is to a modest extent dependent on the magnitude of the measured distance, we compare the median degrees-to-cubits ratio for the reports in which fractions of cubits (always 1/2, 2/3, or 5/6) are attested with the median degrees-to-fingers ratio for the reports in which distances between 8 or 10 and 20 fingers are attested:

fractions of cubit	113 reports	2.54°/cubit
fingers (8 to 20)	109 reports	0.102°/finger
fingers (10 to 20)	73 reports	0.098°/finger

2.54/0.102 $\approx$ 24.9 cubit/finger
2.54/0.098 $\approx$ 25.9 cubit/finger

Hence we may securely consider the finger to be convertible to 1/24 cubit in discussing the observation reports.

As a first try at estimating the degree equivalent of the cubit, we now tabulate in Table 10 the number of reports and the median degree-to-cubit ratio for each attested cubit distance, combining all preserved cubit and finger measurements. The column to the right of the medians gives the mean absolute deviation from the median *distance* in degrees of the actual latitudinal distances for all passages reporting the cubit distance in question; this is a measure of the spread of actual distances that were likely to be reported as a particular number of cubits or fingers, i.e. a measure of the accuracy of the measurements. The last column estimates the standard error of the median ratio, which is a measure of the accuracy with which the median we have obtained approximates the median one would obtain from an indefinitely larger body of Babylonian reports.[45] In the last rows of the table, the same information is tabulated for the aggregate of all reports with 4 cubits or less, and for all reports.

Obviously the frequency with which particular distances were reported was not dependent purely on astronomical considerations, so that for example a measurement that might most precisely have been reported as 5 fingers would often have been reported as 4 or 6. This means that the "preferred" measurements such as 1 cubit are on average less precise than others. On the other hand, the median ratios for the most poorly attested measurements are statistically unreliable; hence we disregard those values for which the number of reports is ten or fewer.[46]

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44 Steele 2003.

45 The standard error of median is calculated as $1.253\sigma/\sqrt{n}$ where σ is the standard deviation of the data and n is the number of data values. This estimate assumes normal distribution, and is probably an overestimate for the ratios arising from division of small values in the first lines of Table 11.

46 I suspect that the anomalous single report with 2 cubits 5 fingers is a textual error.

Table 10. Median degrees-to-cubits ratios according to distance reported

size of measurement	number of measurements	median ratio (r_{median})	mean abs. dev. with respect to median line	estimated standard error of median
1 finger	25	4.97	0.14	1.25
2 fingers	53	3.90	0.32	1.10
3 fingers	9	4.41		
4 fingers	41	2.94	0.36	0.74
5 fingers	8	3.08		
6 fingers	43	2.84	0.21	0.24
8 fingers	37	2.67	0.34	0.54
10 fingers	34	2.45	0.18	0.15
12 fingers	69	2.65	0.37	0.16
14 fingers	16	2.25	0.18	0.13
16 fingers	45	2.41	0.31	0.15
20 fingers	22	2.25	0.30	0.13
1 cubit	66	2.28	0.80	0.23
1 cubit 2 fingers	1	2.26		
1 cubit 4 fingers	25	2.40	0.41	0.10
1 cubit 6 fingers	5	2.49		
1 cubit 8 fingers	21	2.27	0.53	0.15
1.5 cubits	58	2.28	0.66	0.13
1 cubit 16 fingers	21	2.17	0.79	0.16
1 cubit 20 fingers	10	2.50		
2 cubits	67	2.28	0.94	0.10
2 cubits 5 fingers	1	1.54		
2 cubits 8 fingers	10	2.21		
2.5 cubits	59	2.26	0.40	0.08
2 cubits 16 fingers	24	2.30	0.48	0.07
2 cubits 20 fingers	4	2.22		
3 cubits	80	2.34	0.83	0.05
3.5 cubits	46	2.29	0.98	0.07
3 cubits 16 fingers	1	2.24		
4 cubits	65	2.26	0.89	0.05
4.5 cubits	20	2.05	0.73	0.06
5 cubits	19	2.07	1.16	0.09
5.5 cubits	2	1.91		
6 cubits	5	1.97		
$0 < d \leq 4$ cubits	966	2.38	0.61	0.08
all	1012	2.35	0.64	0.08

The median ratios tend to decline asymptotically, levelling off at about 2.3 before dropping abruptly to about 2.0 for measurements larger than 4 cubits. The asymptotic decrease suggests that there may have been a tendency to overestimate all distances by a constant amount. This hypothesis can be tested by applying linear regression separately to the "above" reports and "below" reports, or better by changing the signs of the reported and modern-theory distances for the "below" reports before combining with the "above" reports. Previously, Fatoohi and Stephenson found a slope of 0.092°/finger (implying a cubit of 2.2°) and intercept of +0.2° from linear regression applied to the absolute values of both reported and modern-theory distances for approximately 200 reports in which the measurement is reported only in fingers.[47] Their intercept is artificially raised (and their slope reduced) by their practice of taking absolute values of both quantities, since when the latitudinal distance was small relative to the elongation, it was possible for the observer to report a direction opposite to the true latitudinal difference between star and planet.[48] I therefore have taken the absolute value of the reported distance d_{cubits} (as the independent variable) and multiplied the modern-theory latitudinal distance $d_{degrees}$ by the sign of d_{cubits} (i.e. positive means same direction as reported, and negative means opposite direction), and obtained the following regression equation for 966 passages in which the reported distance was less than or equal to 4 cubits:

$$|d_{degrees}| = |2.27 d_{cubits}| + 0.13$$

This equation appears to describe very well the behaviour of measured distances up to 4 cubits (Figs. 16–17). The mean absolute deviation with respect to this line for all the reports is 0.63, the standard error about the regression line (a measure of the typical residual of the points with respect to the fit) is 0.96, the standard error of the slope is 0.03, and the standard error of the intercept is 0.05.[49] As confirmation of the validity of this line, we find that it successfully predicts the median degree-to-cubit ratios in Table 10 for $d_{cubits} \leq 4$ by the relation:

$$r_{median} = (2.27 d_{cubits} + 0.13)/d_{cubits}$$

A linear relation between $d_{degrees}$ and d_{cubits} is, of course, what one would expect if the observational instrument was graduated in uniform angles (for example a graduated ring or arc). However, measuring along a uniformly graduated straight ruler or string would also have produced a relation indistinguishable from linearity, since the angles measured are always rather small. For example, if one measured using a ruler held so that the part of it where one end of the measured arc begins is perpendicular to the radius from the eye, then $d_{degrees}/d_{cubits}$ for $d_{degrees}$ = 10° should, disregarding other errors, be 0.990 ($d_{degrees}/d_{cubits}$ for $d_{degrees}$ near 0°), which is too small an apparent reduction of the unit to detect from such data as we have.

For measurements above 4 cubits, the median ratio drops significantly to a near constant of close to 2 (there is not enough spread in the measurement values to permit a meaningful regression to test for an intercept). This fact suggests that the method or instrument that the Babylonians used to measure distance between planet and star was different for larger intervals. It seems likely that they were not aware of the inconsistency in the effective size of their unit.

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47 Fatoohi and Stephenson 1998.

48 I am indebted to John Britton for this observation.

49 Fatoohi and Stephenson 212 also calculate intercepts for each planet separately, and argue from the lack of correlation between these values and the planets' brightnesses that the intercept is not due to an optical effect. One cannot, however, establish reliable intercepts for single planets because the number of reports becomes too small to obtain consistent results from different data sets.

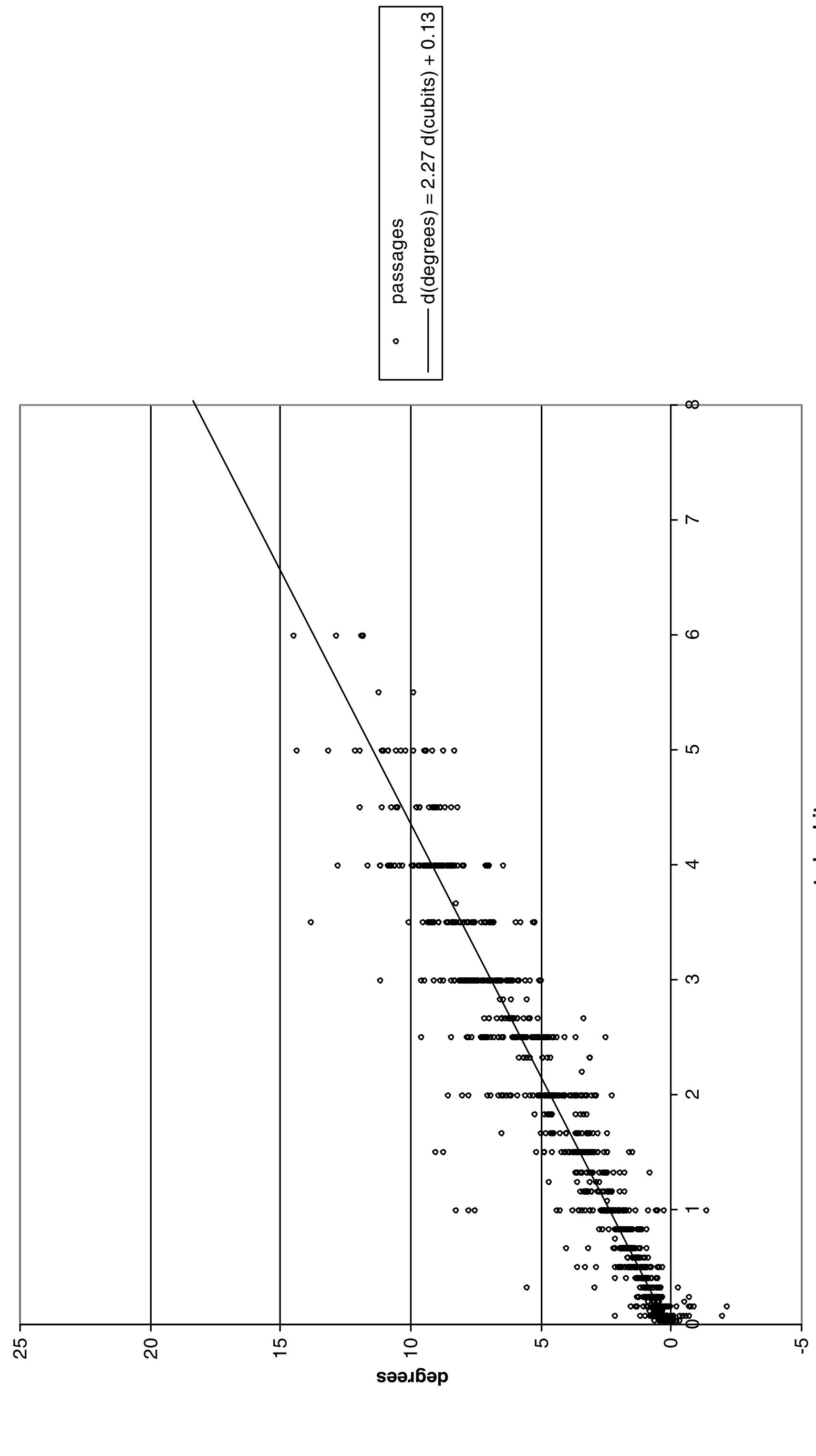

Fig. 16. Latitudinal distances: modern-theory against reported values

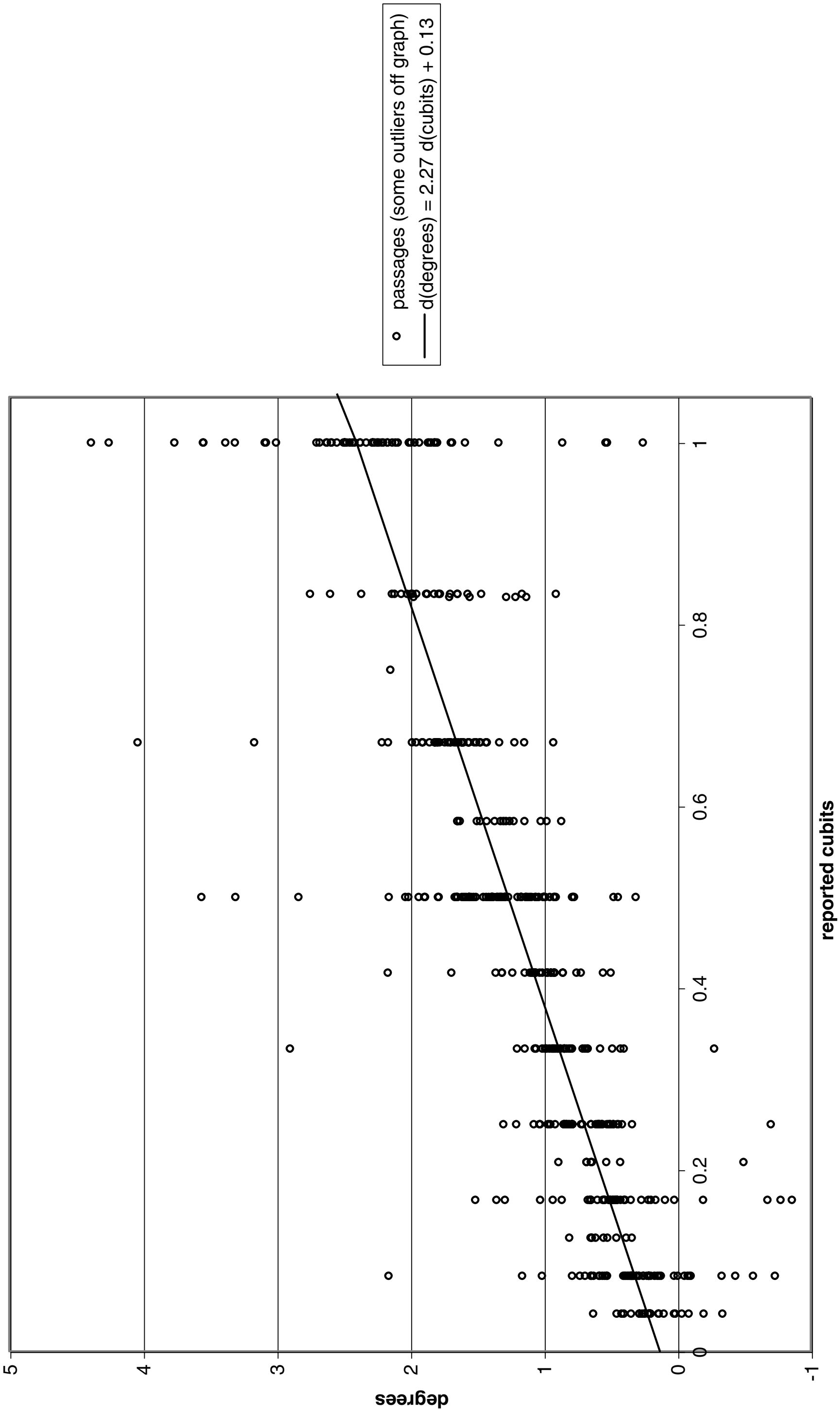

Fig. 17. Latitudinal distances (small values)

Table 11. Median degrees-to-cubits ratios according to date

date range	number of measurements	median ratio (r_{median})	mean abs. dev. with respect to median	estimated standard error of median
$y < -300$	276	2.39	0.56	0.14
$-300 \leq y < -200$	269	2.34	0.71	0.15
$-200 \leq y$	467	2.34	0.66	0.13

There was no significant change in the size of the cubit or in the quality of the measurements during the interval of more than three centuries covered by our data, as shown by Table 11. The temporal consistency of the unit shows that there must have existed some stable standard against which measurements were calibrated. This could have been inherent in the instrument or instruments, or observers may have been trained to calibrate distances by a fixed reference such as the distance between pairs of specific bright stars.

We therefore conclude that the degree equivalent of the Babylonian cubit is approximately 2.27°. This value is slightly lower than the estimates given by Graßhoff, approximately (2.4±0.1)°/cubit, apparently obtained by taking the mean of degree-to-cubit ratios for 427 individual reports.[50] Part of this difference may be attributed to the fact that Graßhoff"s estimate assumes a zero intercept.

In theoretical texts the Babylonians apparently treated the cubit as convertible to 2° exactly.[51] We do not know whether this conversion ratio also applied to their analysis of observational data. However, it is suggestive that when Greek astronomers adopted the Babylonian metrology for distances between heavenly bodies, they apparently believed that the cubit should be equivalent to 2°. Thus when Hipparchus used an astrometrical unit called a "cubit" (*pêchys*) in his astronomical and geographical work, the degree-equivalent of this unit was very close to 2°, and in a lost work Ptolemy is reported to have asserted that the degree-equivalent of the "cubit" (again *pêchys*) in Babylonian Normal-Star observations was 2°.[52] If the Greeks learned this from the Babylonians, it would appear that the Babylonians based their degree-equivalent on their measurements of longer intervals.[53]

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[50] Graßhoff 1999, 137.

[51] Steele 2003.

[52] The most abundant evidence for Hipparchus' cubit is from positional data for 45 stars in his extant *Commentary on the Phenomena of Aratus and Eudoxus*, from which Duke (2002, 429 note 13) computes that 1 cubit = 1.94° ± 0.15°. A 2° cubit is confirmed by Hipparchian computed data expressed in cubits reported by Strabo (2.1.18 and 2.5.42), whereas Hipparchian measured data expressed in fingers and cubits reported by Ptolemy, Almagest 7.1 (Toomer 1984, 322–324 with note 5) are inconclusive. For the marginal note in manuscripts of the *Almagest* mentioning Ptolemy's degree-equivalent for the Babylonian cubit, see Jones 2004.

[53] Or perhaps the Babylonians made their larger measurements using an instrument graduated in degrees, and converted to cubits by halving. For the rare and generally early Babylonian observation reports using degrees (UŠ) instead of cubits, see Appendix 5.

10. Observations of stations and estimation of longitudes

At a planetary station, the planet will normally be a measurable distance from the nearest Normal Star both in longitude and latitude. Collection B comprises 155 reports of stations of Mars, Jupiter, and Saturn that contain at least one preserved distance. Among these, 60 are known to have given distances in two directions (behind/in front and above/below), 8 certainly had only a preserved distance above or below, and 52 certainly had only a preserved distance in front or behind.[54] In all there are 124 preserved measurements of distance in front or behind, and 75 measurements of distance above or below. Drawing on the preceding analysis of passages, we may assume that distance above or below is a measure of latitudinal difference between the planet and the Normal Star, and that distance behind or in front is a measure of the elongation of the planet from the passage point of the star. The reported distances behind or in front never exceed 4 cubits.

The distances recorded in the reports of stations are consistent with the degree equivalent of 2.27° for the cubit obtained in the preceding section, when one makes due allowance for the larger errors that apply to a much smaller set of data. As we did for the passages, we carry out a linear regression taking the absolute values of all reported measurements, changing the signs of the corresponding modern-theory distances when the measurement is negative. Moreover we exclude from consideration the relatively few measured distances greater than 2.5 cubits, since these are statistically unreliable but would strongly influence the regression line. From 111 measurements in the east-west direction, we find $|d_{degrees}| = |2.26 d_{cubits} + 0.17|$, while from 53 measurements in the north-south direction, we find $|d_{degrees}| = |2.44\ d_{cubits} + 0.07|$. Combining the two sets of measurements, we obtain $|d_{degrees}| = |2.33\ d_{cubits} + 0.12|$. The standard error about the regression line for this last is 1.29; the standard error of the slope is 0.13; and the standard error of the intercept is 0.18. Hence we can be reasonably confident that the cubit in station reports has the same degree-equivalent as in passage reports, but we cannot be sure whether there is a constant component in the measurements, though one would certainly expect one.

Since we have reason to believe that the Babylonians would have converted cubit measurements to degrees assuming a simple 2° equivalence, it is worthwhile to see what effect the use of this less accurate conversion would have on observational data. Using the complete collection of station measurements in all directions, the mean absolute deviation of the modern-theory distances from the line $|d_{degrees}| = |2.27 d_{cubits} + 0.13|$ is 0.89°, while the mean absolute deviation from the line $d_{degrees} = 2\ d_{cubits}$ is 0.99°. This surprisingly small difference reflects the circumstance that small measurements predominate.

The practice for measuring, or at least for recording, distances at stations was roughly as follows. Normal Stars in the core 28 as well as certain of the additional stars (θ Cnc,

[54] 23 reports have a preserved distance ahead or behind and may have originally had a distance above or below; 10 have a preserved distance above or below and may have originally had a distance in front or behind; and two have a distance above or below and an indication that the planet was "a little" in front of or behind the star.

the front and rear Sagittarius quartets, and the Ribbon of the Swallow) were used on a regular basis to locate stations; attestations of the remaining Normal Stars are very rare. If the planet was close to being directly above or below the nearest Normal Star, the observer might record both coordinates, or just the distance above or below (sometimes with a vague statement that the planet was "a little" ahead or behind), or occasionally just the distance in front or behind. In most instances where only the latitudinal coordinate was recorded, the difference in longitude was half a degree or less; the largest difference attested is 1.1°. When the longitudinal difference was larger, up to about 10°, the observer recorded both coordinates in about half the cases, and otherwise just the distance in front or behind (Fig. 18). About one station in six was recorded with a vague location in a zodiacal sign or in the beginning or end of a sign. For the majority of these "vague" stations it turns out that the planet was within, often well within, 10° of the nearest Normal Star; possible reasons for omitting measured distances in these cases would be that the observing conditions were poor or that the report is actually a prediction, not an observation. However, almost all stations occurring in Aquarius and the first half of Pisces are reported vaguely, although many of them took place within 10° of one of the "baskets". The distribution of measured and vague station reports is shown in Figs. 19–20.

We are now in a position to consider how accurately the Babylonian observers could have determined planetary longitudes in general on the basis of observed distances from Normal Stars. The procedure would presumably be to multiply the observed distance of the planet behind or ahead of the star by an assumed cubit-to-degree ratio, and to add the product to the star's presumed longitude obtained from a Normal Star catalogue. Hence the computed longitude would incorporate errors arising from three separate components: the assumed longitude of the star, the assumed degree equivalent, and the measurement in cubits. If the Sachs and RSW catalogues are actually parts of the same catalogue, then the mean absolute deviation of the catalogue's longitudes was, very roughly speaking, about 1°. We have also seen that if the Babylonians assumed a degree-equivalent of 2.3° for the cubit, the mean absolute deviation of their calculated elongations would have been about 0.8° if the planetary positions they were observing were distributed similarly to the stations with respect to the Normal Stars, that is, with a mean absolute elongation of roughly 3°. If they assumed a degree-equivalent of exactly 2°, the value attested in theoretical texts, the mean absolute deviation would increase slightly, to about 0.9°. We can expect that planetary longitudes derived by the Babylonians from Normal Star observations will typically have been in error, relative to whatever longitudinal norm they had, by between 1° and 2°.

This expectation must further be qualified by the stipulation that the planet was within 4 cubits (roughly 10°) of a Normal Star. The observational records maintained by the Babylonians would in fact have provided a rather narrow basis for theoretical work dependent on longitudes, because the only events of significance for the planets' synodic cycles for which they regularly recorded distances to Normal Stars were stations. Further, we have noted that longitudinal information was unavailable for some stations throughout the ecliptic, and for almost all stations in a region covering about one eighth of the ecliptic. This means that methods of analysis relying on the cumulative record of occurrences of stations in different regions of the ecliptic would have been difficult to carry out.

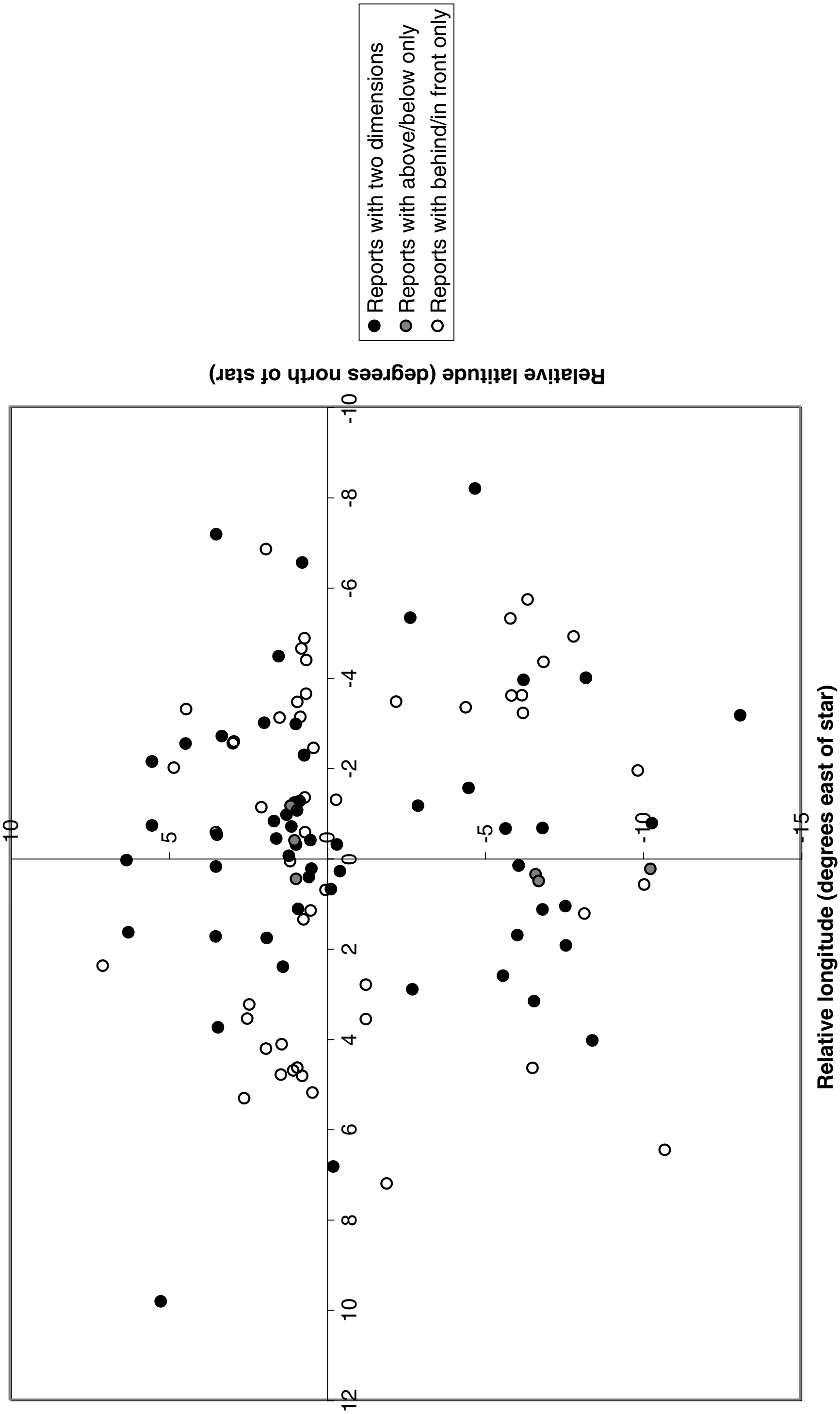

Fig. 18. Locations of stations relative to Normal Star

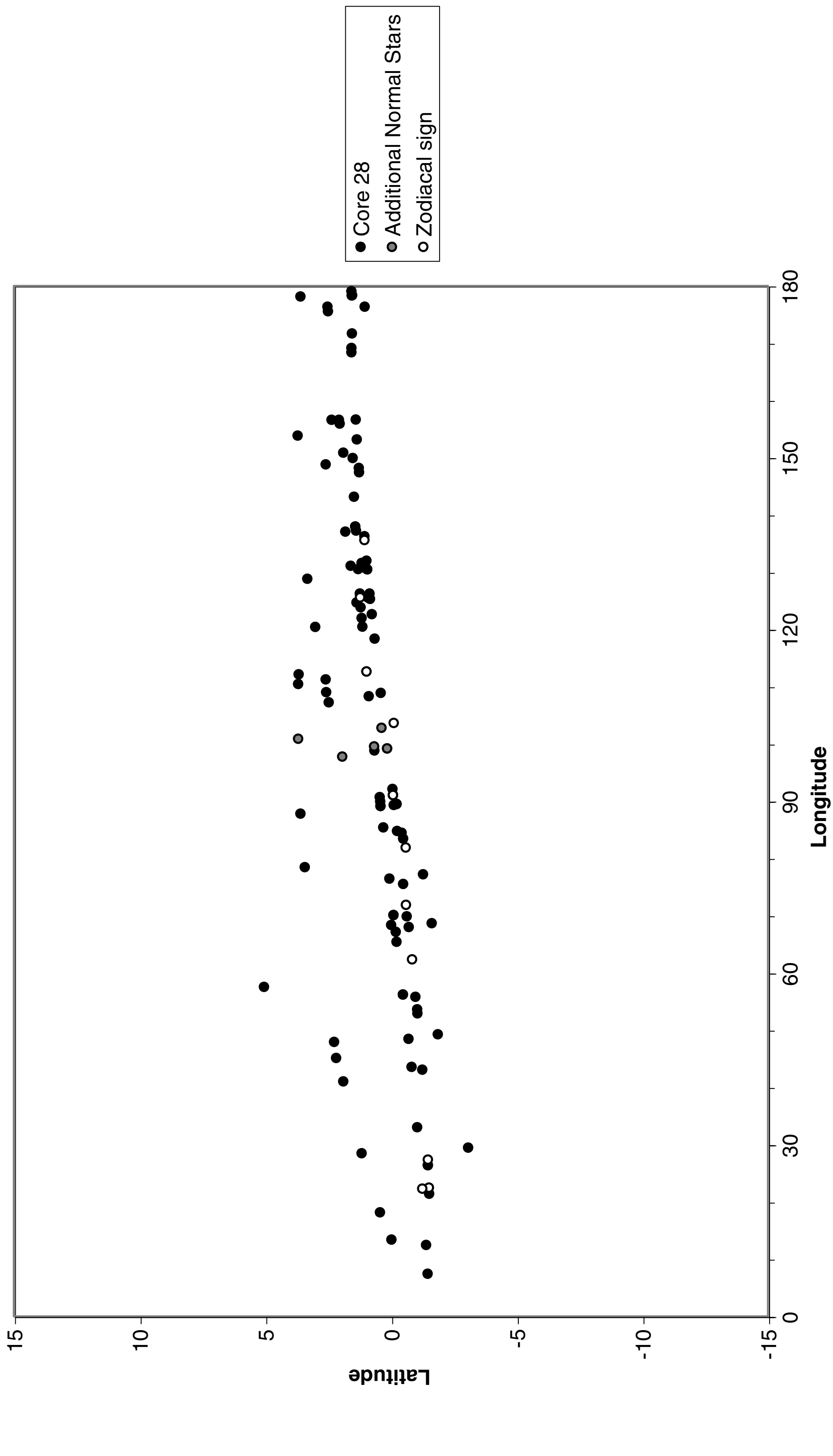

Fig. 19. Sidereal locations of stations (1)

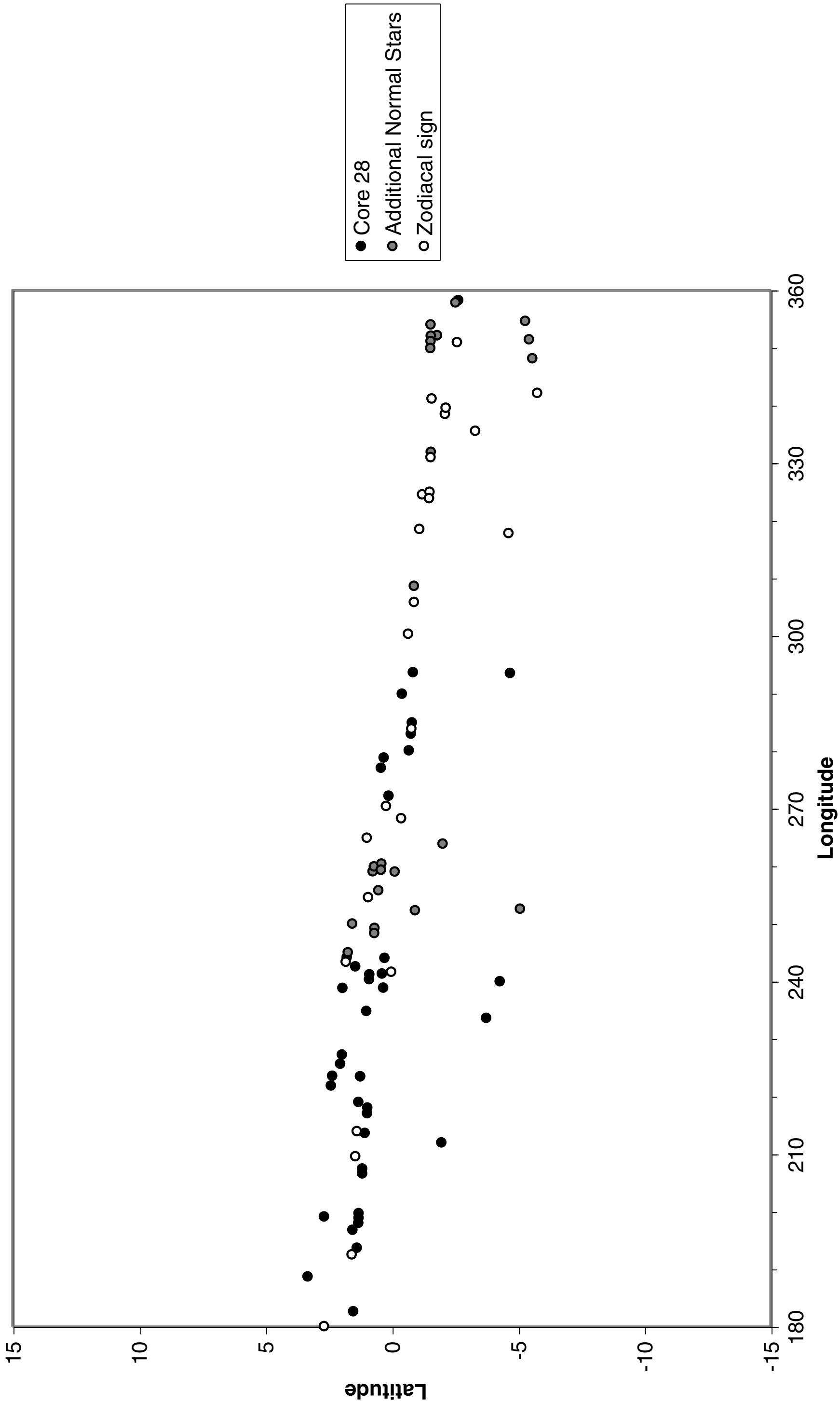

Fig. 20. Sidereal locations of stations (2)

Any attempt to reconstruct the steps by which the Babylonians derived their mathematical planetary theories must, in our present state of knowledge, be speculative. Insofar as they used observed planetary longitudes as one element of their theoretical work, they could either have relied on the same past observational records that we have representative fragments from, that is, Diaries, Goal-Year Texts, and excerpt texts, or they could have made special observations. In the former case, they would have had to work around the large gaps in their data. In the latter case, they could have had a larger star list, but the expanded observational practice required for developing planetary models manifestly had no influence on the choice of observations to record in the Diaries.

Appendices

1. Coincidental Normal Star passages and sign-entries in observation texts

The following is a list of records of planetary sign-entries for the three zodiacal signs Gemini, Cancer, and Aquarius in the Diary texts for which a contemporary observation record of a passage of the relevant Normal Star is also preserved. The reports listed as (b) ii have the only divergent dates, if the reading of the sign-entry's date is correct.

a. Gemini 0°/ζ Tau
   i. Diary -204 C obv. 11, Venus above ζ Tau on night of S.E. 107 I 10? (day number is lost, but report immediately precedes record for day part of I 10). Diary -204 C rev. 10, Venus enters Gemini on S.E. 107 I 10.

b. Cancer 0°/β Gem
   i. H83 (BM 34944) 2′, Mars below β Gem on night of S.E. 122 II 6. Diary -189 A obv. 11′, Mars enters Cancer on S.E. 122 II 6.
   ii. Diary -140 A obv. 11, Mars below β Gem on night of S.E. 171 I 16. Diary -140 A obv. 18, Mars enters Cancer on S.E. 171 I 19? (reading of day number is uncertain).
   iii. Diary -140 A obv. 13, Venus below β Gem on night of S.E. 171 I 21. Diary -140 A obv. 18, Venus enters Cancer on S.E. 171 I 21.
   iv. Diary -124 A obv. 14′, Mercury below β Gem on night of S.E. 187 II 13. Diary -124 A obv. 22′, Mercury enters Cancer on S.E. 187 II 13.
   v. Diary -108 B obv. 9, Venus below β Gem on night of S.E. 203 I 16. Diary -108 A obv. 11′, Venus enters Cancer on S.E. 203 I 16.
   vi. Diary -105 A obv. 9′, Venus below β Gem on night of S.E. 206 I 27. Diary -105 A obv. 12′, Venus enters Cancer on S.E. 206 I 27.
   vii. Diary -105 A obv. 24′, Mercury below β Gem on night of S.E. 206 II 13. Diary -105 B obv. 29′, Mercury enters Cancer on S.E. 206 II 13.
   viii. Diary -77 A rev. 8, Venus below β Gem on night of S.E. 234 IV 7. Diary -77 A rev. 17, Venus enters Cancer on S.E. 234 IV 7.

c. Aquarius 0°/δ Cap
   i. Diary -193 B rev. 6′, Venus above δ Cap on night of S.E. 118 XII 9. Diary -193 B rev. 13’, Venus enters Aquarius.
   ii. Diary -134 B rev. 12′, Venus above δ Cap on night of S.E. 177 XII 7. Diary -134 B upper edge 2, Venus enters Aquarius.

iii. Diary -107 D obv. 19′, Venus 2 fingers east of δ Cap on night of S.E. 204 IX 2 (day number missing but certain from context). Diary -107 D obv. 35′, Venus in Capricorn on S.E. 204 IX 1 and 2, in Aquarius rest of month.

For the following records of sign-entries, there appears to have been no corresponding record of an observation of the relevant Normal Star passage, either on the same date or close to it. Unless the Normal Star passage was observed but not recorded in the Diary, these sign-entries must have been predicted in some other manner.

Diary -182 C rev. 10, Mercury enters Aquarius on S.E. 129 XI 24. (The only report for the night of XI 24 is that the weather was cloudy.)
Diary -140 D rev. 16, Venus enters Aquarius on S.E. 171 XI 7. (The moon was observed on the night of XI 7; there is no indication of bad weather.)
Diary -123 A obv. 17’, Venus enters Cancer on S.E. 188 III 8. (The moon was observed on the night of III 8; no indication of bad weather.)
Diary -77 A rev. 4–5, Venus enters Gemini on S.E. 234 III 12. (Mars was observed on the night of III 12; no indication of bad weather.)

2. *Agreement between PD3 and months in the Diary texts*

Following each Diary text in Sachs and Hunger 1988, 1989, and 1996, Hunger lists the Julian calendar dates of the first day of each Babylonian month that is securely fixed by the contents of the Diary, indicating where a month beginning does not coincide with the theoretically derived date in PD3. Table 12 displays the rate of discrepancies over successive quarter-centuries beginning with −399. Before −200 the mean rate of discrepancies is roughly 0.09, which means that a dating of an observation report based on PD3 can be expected to be one day off roughly one time in eleven. In 24 of these discrepancies the date according to PD3 is later than the true date, and in 12 the PD3 date is earlier. After −200 the mean rate drops to roughly 0.03, so that a dating based on PD3 will be one day off only about one time in thirty-three. Nine of the twelve discrepancies during this later interval have PD3 giving dates earlier than true.

Since it is not likely that the lunar visibility theory of Schoch that underlies PD3 is much more applicable to dates after −200 than before −200, the abrupt change in the rate of discrepancy must reflect a change in the way that the Babylonians determined the beginnings of their months. We can be sure that they did not depend on unaided observation of the lunar crescent, since month lengths are invariably either 29 or 30 days regardless of weather. It would seem that about −200 the rules for regulating the months were revised, resulting in a pattern that agrees remarkably well with modern theoretical expectations.

The preponderance of late PD3 month-beginnings over early ones in the period before −200 should cause a mean bias of less than one hour in calculations of astronomical positions for large bodies of observations depending on PD3. For the period after −200 the mean bias is less than half an hour in the opposite direction. Clearly these are small effects, and there would be almost nothing to be gained by refining the visibility theory of PD3.

Table 12. Disagreements between PD3 and Diaries

beginning of quarter-century	number of secure months	discrepant months	rate of discrepancy
−399	35	3	0.09
−374	32	2	0.06
−349	30	3	0.10
−324	58	8	0.14
−299	56	2	0.04
−274	61	8	0.13
−249	62	6	0.10
−224	48	4	0.08
−199	106	2	0.02
−174	74	3	0.04
−149	92	4	0.04
−124	65	0	0
−99	67	2	0.03
−74	5	1	0.20

3. Normal Star sightings of Mercury

It is well known that the Babylonians were usually unable to observe Mercury when it was expected to make its morning appearance in much of Aries and Taurus, or when it was expected to make its evening appearance in Libra or the beginning of Scorpio. If one asks under what conditions they were able to observe Mercury in the vicinity of a Normal Star, which would be necessary to make a direct measurement of the planet's longitude, it turns out that the ranges of longitude in which such observations were possible are considerably narrower than the ranges within which the planet was itself visible. To illustrate this, Table 13 shows the number of dated evening and morning Normal Star passages of Mercury for each Normal Star in Collection A (there are in fact no attested passages of Mercury by the additional Normal Stars discussed in Section 6 above). With rare exceptions, Mercury was observed in the evening only with the brighter stars between η Psc and α Leo, corresponding to dates from early March to early July; and it was observed in the morning only with the brighter stars between α Leo and δ Cap, corresponding to dates from mid August to mid February. There is also a striking assymetry in that the number of morning passages is less than half the number of evening passages. This imbalance is partly, but I believe not entirely, attributable to the higher concentration of bright Normal Stars in the part of the ecliptic where evening observations of Mercury were favoured.

4. Dating of H53

The reverse of H53 (BM35196) contains reports of passages and synodic phenomena of Venus in a series of years of which the first for which there are significant remains

Table 13. Passages of Mercury

Normal Star		Evening	Morning
c1	η Psc	3	0
c2	β Ari	6	0
c3	α Ari	4	0
c4	Pleiades	8	0
c5	α Tau	11	0
c6	β Tau	15	0
c7	ζ Tau	10	0
c8	η Gem	14	0
c9	μ Gem	15	0
c10	γ Gem	13	0
c11	α Gem	15	2
c12	β Gem	21	0
c13	δ Cnc	3	0
c14	ε Leo	9	0
c15	α Leo	11	2
c16	ϱ Leo	0	1
c17	θ Leo	1	0
c18	β Vir	0	1
c19	γ Vir	0	3
c20	α Vir	0	4
c21	α Lib	0	6
c22	β Lib	0	6
c23	β Sco	0	7
c24	α Sco	0	10
c25	θ Oph	0	7
c26	β Cap	1	9
c27	γ Cap	0	3
c28	δ Cap	0	4
	Total	159	66

is numbered 18, and the last is 21. Allowing for a small number of minor discrepancies (textual errors?), the reports are consistent with a possible pattern of motion and visibility phenomena for Venus. The only good match with actual dates in the Babylonian calendar that I was able to find, taking also into account the fact that year 20 has an intercalary month XII_2, has year 18 = S.E. 24 (−287/−286) so that year 1 = S.E. 7.

The most decisive evidence for this dating is the correspondence of the dates of Venus' passages of Normal Stars in the text with passage dates calculated by modern theory. There are seventeen passages in the text for which the date is preserved and the identity of the star is secure. Of these, nine give dates that, if assigned to the proposed years, correspond to either the night before or the night after Venus had the same longitude as the star; three are one day earlier than the night before; two are one day later than the night after; and two are two days later than the night after (one of these last is a passage of γ Leo, for which late passage is expected). The only large discrepancy is the nine-days-early passage of γ Vir stated to take place on year 21 IV 9, probably a textual error for 21 IV 19 (Rev. III 16′-17′). The dates of Venus' appearances and disappearances are also close to dates computed by modern theory.

S.E. 7 was in fact the first effective year of Seleucus I's rule, notwithstanding the official backdating of his regnal year count to S.E. 1 that was adopted fairly early in his reign. An alternate practice of counting years such that year 1 = S.E. 7 is attested in Diary -302/301 (Rev. 21, "year 4" = S.E. 10), consistent with the prolonged counting of regnal years of Alexander IV after his death, attested in other texts.[55] H53 shows that the two conventions coexisted for at least a decade and a half.

The obverse of H53, containing observation records for Mercury, is in terrible condition, with doubt adhering to a majority of the critical readings. Allowing, therefore, for a fairly high rate of apparent discrepancies, decent agreement with modern theory is obtained if the years in col. I are Philip Arrhidaeus 3–4 (−320/319 to −319/318), and those in col. II are Philip 7 to Alexander IV 2 (−316/315 to −314/313). The regnal year indication at Obv. II 26', "MU 1 *An*", probably refers to Antigonus, although one would expect the year in question to be identified as year 3 of Antigonus.[56] A difference of between thirty and forty years between the Mercury and Venus data on the same tablet could be explained by the difference between the 46-year Goal-Year period for Mercury and Venus' 8-year period, so that the information in the tablet would have been directed towards predictions of planetary phenomena in a range of years including −279/278 through −268/267.

5. *Early planetary reports and reports from sites other than Babylon*

Most of the surviving reports of planetary observations involving Normal Stars date from the late fifth century and after, and come from Babylon; it is with the practice of observation represented in these texts that the present paper is chiefly concerned. This appendix gives brief comments on texts that contain reports older than the late fifth century, or that were found at other Babylonian sites.

Four texts have reports from the seventh century. Interestingly, the text with the oldest material most closely resembles the practice of the late period, with reports of planetary passages by about a dozen identifiable stars, most of which were included among the later Normal Stars, and with distances in cubits and fingers. The other texts show considerable variation in the choice and detail of planetary observation reports. One station is reported with a distance in cubits from a star. Interestingly, distances from stars were also sometimes recorded for first appearances, a practice that became rare in the later period. We also find in this period that the unit UŠ (i.e. degree) is sometimes used instead of the cubit.

After an undocumented half-century we have three texts with reports from the interval −576/−575 through −566/−565. At this time planetary passages and stations were

[55] Aaboe, Britton, Henderson, Neugebauer, and Sachs 1991, 30–31.

[56] -314/313, though the first year after the death of Philip, was regularly counted as the third year of Antigonus' generalship; cf. Boiy 2001.

regularly reported with distances from stars in cubits and fingers; the repertoire of reference stars had a large overlap with the later Normal Star list but was not identical to that list. Among the texts pertaining to the second half of the sixth and the first half of the fifth century, the most anomalous in comparison to later practice is SpTU 5.268, a tablet from Uruk that shows continued use of UŠ alongside cubits, as well as attempts at precise locations of first and last visibilities. I know of only one later use of UŠ in a Normal Star observation, in Diary -368 (Rev. 10'), where the distance of Mars behind β Gem is reported in UŠ, while its distance behind Venus is given in cubits. It is not clear when the standard Normal Star list came into use in Babylon, but a date somewhere about the middle of the fifth century would make sense of the texts that we possess. The lists used in Uruk in the fourth and second century were practically the same.

H52 (BM41222)

Presumed from Babylon. The text comprises three sections: passages and other phenomena (probably first and last appearances and stations) of Saturn from −674/−673 through −668/−667; reports in which both Mercury and Mars are mentioned from −680/−679 through −618/−617; and passages of Mars from −648/−647 through −611/−610. Distances "above" and "below" are reported in cubits and fingers. Stars used include Pleiades, α Tau, ζ Tau, stars in Gemini (apparently γ Gem and η Gem), δ Cnc, α Leo, β Vir, α Vir, α Lib, and the "two small stars of the ears of the Scorpion" ($\omega_1 + \omega_2$ Sco?).

HSM1490 (published Britton 2004)[57]

Presumed from Babylon. The text contains observations of phenomena of Saturn, which when intact covered more than a century. The extant parts cover two widely-spaced intervals, from −667/−666 through −656/−655 and from −569/−568 through −566/−565. In the older part, almost all reports are of first and last appearances, mostly designated as predictions; there is a single dated position, not associated with a first or last visibility, "towards the middle of the crab." In the later part, reports are given of first and last visibilities, stations, and acronychal risings. The stations and acronychal risings are located in relation to stars, sometimes but not always with distances in front, behind, above, or below in cubits. Stars used include η Psc, β Ari, α Tau, ζ Tau, and ϱ Leo.

Diary -651

Presumed from Babylon. The oldest surviving fragment of a Diary contains few planetary reports (and no lunar passages). A station of Mars is located (without distance) relative to β Sco, and a few days later its position (without distance) relative to the same star is given. What seems to be a station of Jupiter is reported with a distance in cubits from the "scales" (α+β Lib). On two dates (the second being a near-occultation) the distance between Mars and Venus is reported in fingers.[58]

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[57] I am grateful to John Britton for making this text available to me in advance of his edition.

[58] I so interpret the entry for XII 20 in col. iv 15'-16'. At its nearest visible approach to Venus, Mars was less than 15' away; the "front? of Aries" presumably indicates the general area where the event occurred.

BM76738+76813 (published Walker 1999)

Provenance uncertain.[59] First and last appearances of Saturn covering −646/−645 through −633/−632. Some first appearances are located relative to single stars, including α Leo, γ Vir (misnamed as β Vir), and α Sco. One or (possibly) two distances from stars are given, expressed in UŠ.

SpTU 4.171 (published von Weiher 1993, commentary Hunger 2000 and de Jong 2002)

From Uruk. First and last visibilities and stations of Saturn, covering −576/−575 through −573/−572. The stations are mostly located relative to stars, with distances in cubits. Stars used include θ Oph (apparently designated both as the "tip" and the "bristle" of Pabilsag's arrow), the rear quartet in Sagittarius, the "small star of Pabilsag" and the "container of Pabilsag" (identifications uncertain: Hunger suggests respectively λ Sgr and $\phi+\sigma+\tau$ Sgr, de Jong suggests μ Sgr and λ Sgr, I suggest μ Sgr and $\gamma^2 + \delta + \varepsilon + \eta$ Sgr), and β Cap.

Diary -567

Presumed from Babylon. This is the earliest preserved Diary to contain lunar passages. Passages report distances in front, behind, above, and below in cubits and fingers. Stars used include Pleiades, β Gem, Praesepe, α Leo, θ Leo, β Vir, β Lib, $\beta+\delta$ Sco, α Sco, π Sgr (the "elbow of Pabilsag"), β Cap, δ Cap, ι Aqr ("the small star which stands 3 1/2 cubits behind the Goatfish"), and λ Aqr ("the bright star of [remainder of name lost]"); the text also notes when planets enter and exit the "ribbon of the swallow" and the "ribbon of Anunītu." One station is reported, without location.

H54 (BM36823)

Presumed from Babylon. Observations of Jupiter, preserved parts covering several intervals of two or three years in the range −526/−525 through −489/−488. The reports are chiefly of first and last appearances and stations, with a few passages. Stars used include η Gem, γ Gem, β Gem, Praesepe, α Leo, and α Vir. One preserved passage has no measurement, while the only other seems to be corrupt but uses cubits. The station reports give no distances, but one last visibility gives a distance in cubits (from "the twins," presumably meaning $\alpha+\beta$ Gem), and three first appearances give distances in UŠ. Several of these indications of location were clearly unobservable, and moreover situate Jupiter more than 10° too far east of its actual position, suggesting extensive reliance on prediction.

H55 (BM33066)

Presumed from Babylon. Lunar and planetary (mostly first and last visibility) reports from −522/−521, including a few passages of planets by other planets, with distances in cubits and fingers.

[59] The tablet belongs to an inventory group consisting of texts from Sippar, Babylon, and Borsippa.

Diary -463

From Uruk. The text preserves two lunar passages (one with a preserved distance in cubits), and two planetary first appearances located relative to stars (one with a preserved distance in cubits), but no planetary passages or stations. Stars used include α Leo, γ Vir, and α Vir.

SpTU 5.268 (published von Weiher 1998)

From Uruk. Reports of planetary phenomena (first and last visibilities and stations), eclipses, and solstices, covering −462/−461 through −460/−459. Location relative to stars, often with distances, are reported for first and last visibilities as well as stations. Distances are usually reported in cubits; but for Mars' and Saturn's first visibilities (and apparently *only* these phenomena) the distances are in UŠ. The reported positions for Jupiter's last and first visibilities in −462 are seriously off (as in H54), likely indicating predicted data. Stars used include α Leo, β Vir, α Lib, β Lib, the "head of the scorpion," and the front quartet in Sagittarius.

H56 (BM32299+42083+45674)

Presumed from Babylon. Reports of first and last appearances and passages of Venus, during years ranging from −462/−461 to −392/−391. The passage reports are essentially indistinguishable from reports of the fourth century and after; nevertheless the text exhibits a few interesting features. First, although the text provides a very full framework of calendrical information for all years covered, the reported passages are surprisingly few and seem to concentrate on a few stars, especially in the earlier years. Thus in the first 24 years, out of which more than ten years' worth of the text is extant, there are only nineteen passages (and three entire years with no passage reports at all). The stars mentioned in this part of the text are α+β Ari, the Pleiades (twice), α Tau, β+ζ Tau, α Leo (4 times), α Vir (5 times), α Lib, and α Sco (3 times). In later years γ Cnc, θ Leo, γ Vir, β Sco, θ Oph, and δ Cap are added to the repertoire of stars; but throughout the text there is no year in which more than four passages are reported. All the stars used were among the Normal Stars, and only γ Cnc was not one of the core 28. The text refers to α Lib as the "scales" without qualification, and similarly uses the terms "the head of the hired man" and "the reins of the chariot" without indicating which star is meant. In the last preserved year, −392/−391, Venus is reported to have reached the "ribbon of the fish" without mention of η Psc.

Diary -453

Presumed from Babylon. This small Diary fragment preserves only a single textually damaged passage of the moon by Venus, with a distance in cubits.

H58 (BM32209)

Presumed from Babylon. Reports of passages of the moon by Mars and Saturn, during years ranging from −422/−421 to −399/−398. The reporting of directions and distances appears to follow the standard conventions for the late fifth century and after.

H63 (AO17630)

Reportedly from Nippur. Phenomena of Jupiter, Venus, and Mercury including first and last appearances, passages, and (for Jupiter) stations and acronychal risings, covering −363/−362 and −362/−361. Stars are referred to only in passages, with measurements in cubits and fingers. Stars include α Ari, Pleiades, and β Cap.

H82 (IM44152)

Presumed from Uruk. Phenomena of Jupiter including first and last appearances, stations, acronychal risings, and passages. The reports of stations do not locate Jupiter relative to Normal Stars. The passages follow the same conventions as contemporary texts from Babylon. The Normal Star list used appears to be essentially the same as at Babylon, but with ε+μ Leo referred to as a single object called "the two stars in the beginning of Leo." There are large systematic errors in all the passage reports, implying that these at least are computed rather than observed.

A3456 (published Hunger 1988)

From Uruk. First and last visibilities and passages of Mercury, covering −195/−194 through −179/−178. The reports are very similar in expression to contemporary reports from Babylon, and the Normal Star list used appears to have been essentially the same.

Diary -99C

The text, actually consisting of excerpts from Diaries, may be from Uruk. The excerpts are mostly passages of the moon or a planet by a planet, with distances in cubits and fingers; the only stars mentioned are α Lib (in an eclipse report), and α Sco (in a lunar passage also mentioning Mars).

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