Babylonian computational astronomy

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content

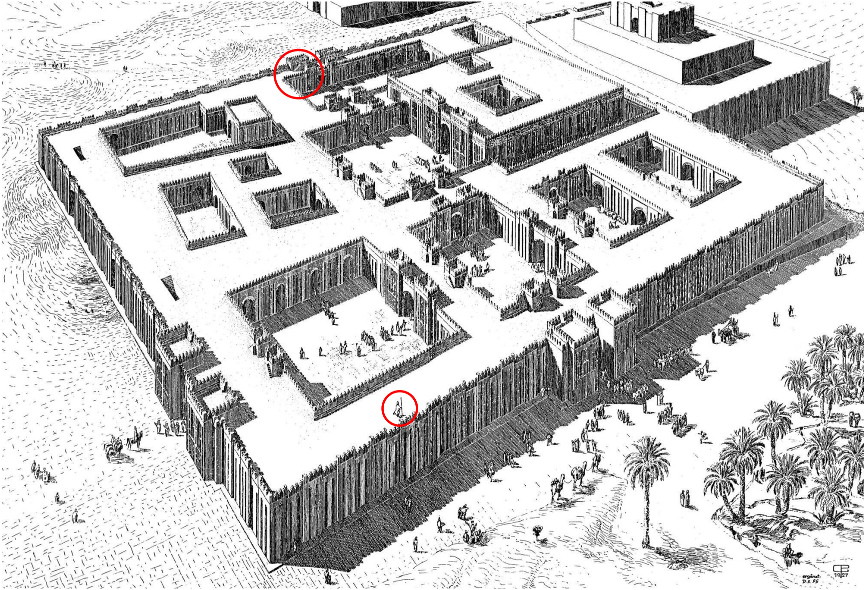
Jupiter

Moon

who were the Babylonian astronomers?

Mesopotamia

Uruk 192 BC

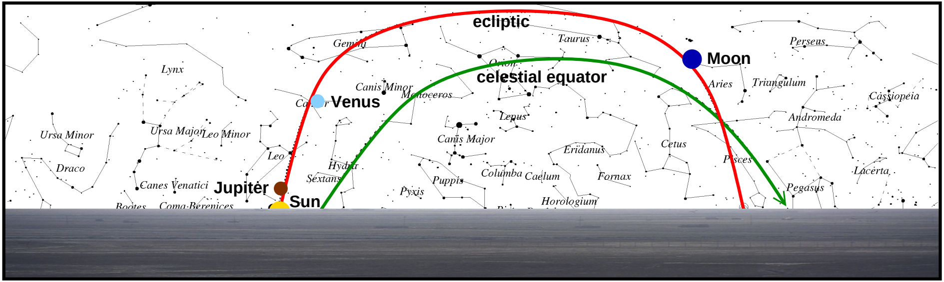


Bīt-Rēš, temple of Anu and Antu

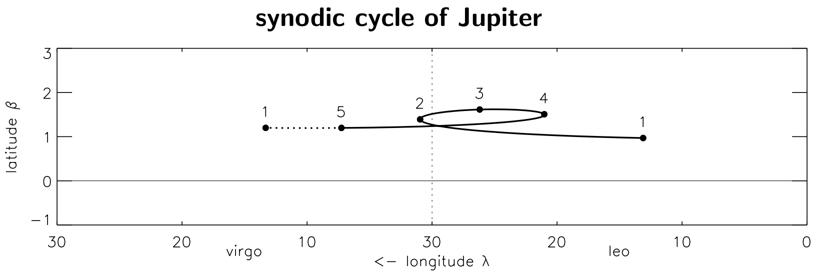
ziqqurat

from observation to computational scheme: Jupiter

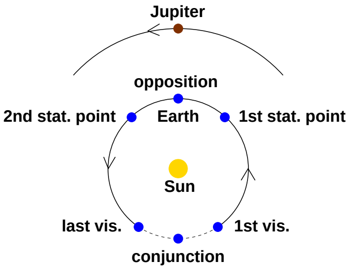
sunrise Uruk 20 august 192 BC



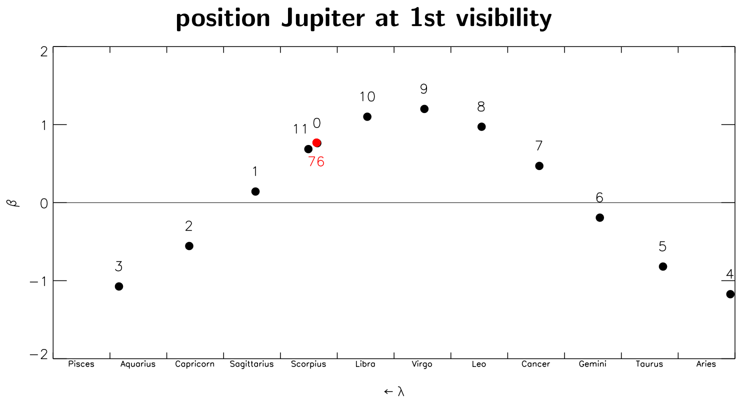
from observation to computational scheme: Jupiter



1	1st visibility	125 d
2	1st stationary point	60 d
3	opposition	60 d
4	2nd stationary point	125 d
5	last visibility	30 d
1		400 d



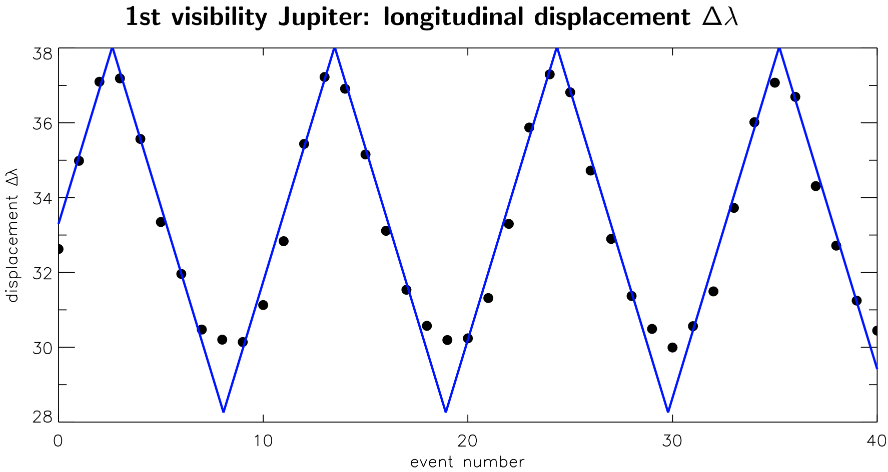
from observation to computational scheme: Jupiter



period relations

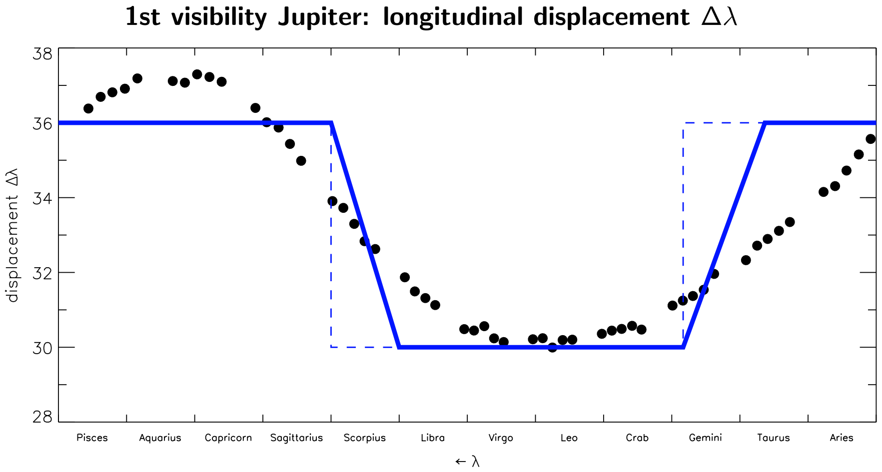
- 11 events = 1 revolution = 12 yr
- 76 events = 7 revolutions = 83 yr (Goal-Year texts)
- 391 events = 36 revolutions = 427 yr (computational astronomy)

from observation to computational scheme: Jupiter



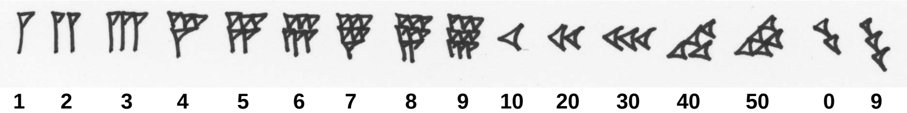
System B: zigzag function

from observation to computational scheme: Jupiter



System A: step function

sexagesimal calculus



- positional notation

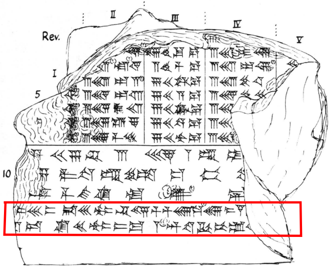
  $600.1 = 6 \cdot 10^2 + 0 \cdot 10^1 + 0 \cdot 10^0 + 1 \cdot 10^{-1}$ decimal [base number 10]

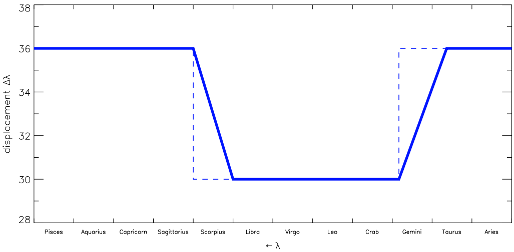
  $= 10 \cdot 60^1 + 0 \cdot 60^0 + 6 \cdot 60^{-1} = 10{,}0;6$ sexagesimal [base number 60]
- in cuneiform: 10.0.6 = relative notation
- addition: 0;59 + 0;2 = 1;1
- multiplication: 10,0;6 × 6 = 1,0,0 + 0 + 0;36 = 1,0,0;36
- division: 10,0;6 / 3 = 10,0;6 × 0;20 = 3,20;2

computational instruction Jupiter System A

BM 34571

Babylon, 2nd c. BC





[From 25 Gemini to 30 Scor]pius you add 30; from 30 Scorpius to 25 Gemini you add 36. Whatever [exceeds 25 Gemini you multiply by 0;50, add to 25 Gemini and put down. Whatever exceeds 30 Scorpius] you multiply [by 1;1]2, add to 30 Scorpius and put down.

times: $\Delta t = 12 \text{ m} + \Delta\lambda + 12;5,10 \text{ d}$

Jupiter: synodic table

AO 6476 + U 104

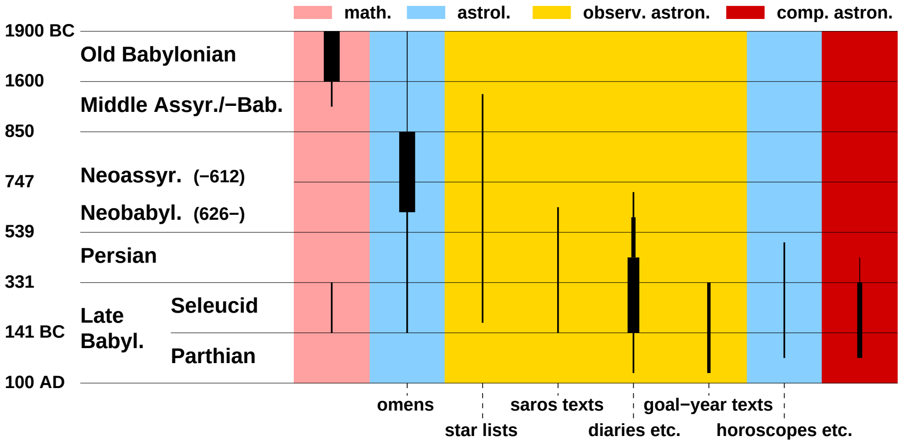
Uruk, written 12 VII 118 SE = 4/5 oct. 194 BC

1st stationary point (System A)

	year SE*	Δt	month	day	λ	zodiacal sign
1	113 (VI_2)	48;5,10	I	28;41,40	8;6	Capricorn
	114	48;5,10	II	16;46,50	14;6	Aquarius
	115 (XII_2)	48;5,10	IV	0;4,52	20;6	Pisces
	116	48;5,10	IV	22;57,10	26;6	Aries
5	117	48;5,10	VI	11;2,20	2;6	Gemini
	118 (XII_2)	45;54,10	VII	26;56,30	5;55	Cancer
	119	42;5,10	VIII	9;1,40	5;55	Leo
	120	42;5,10	IX	21;6,50	5;55	Virgo
	121 (XII_2)	42;5,10	XI	3;12	5;55	Libra
10	122	42;5,10	XI	15;17,10	5;55	Scorpius
	123 (XII_2)	43;16,10	XII	28;33,20	7;6	Sagittarius
	125	48;5,10	I	16;38,30	13;6	Capricorn
	126 (XII_2)	48;5,10	III	4;43,40	19;6	Aquarius

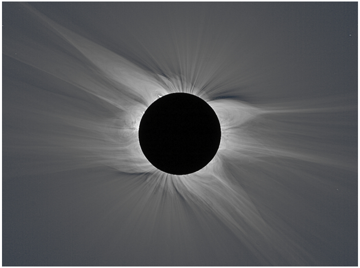
* Seleucid Era; 1 I SE 1 = 2/3 april 311 BC

astronomical, astrological and mathem. text groups

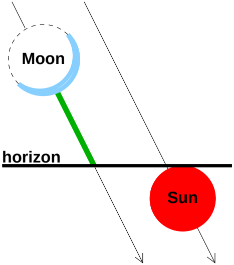


Moon

lunations

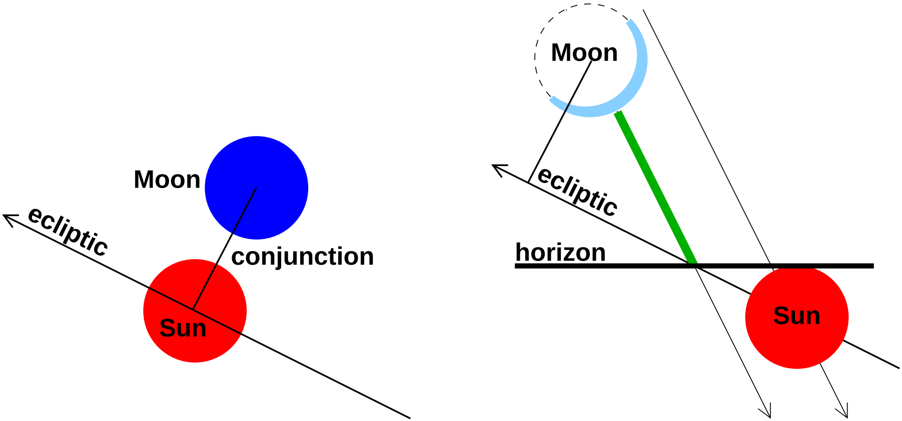


eclipses

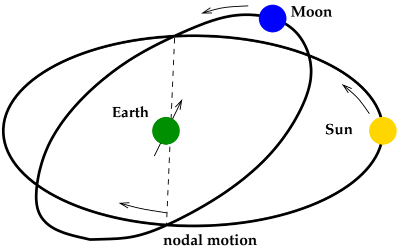


1st visibility

Moon: conjunctions, 1st visibility



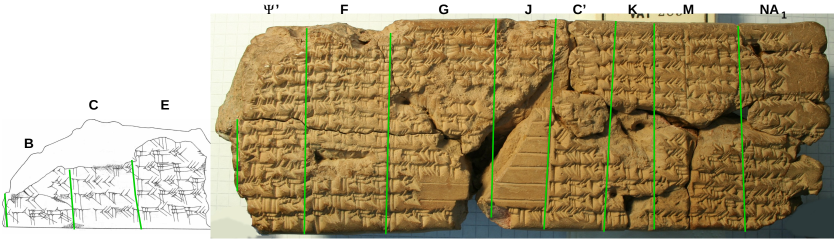
Moon: period relations



- lunar anomaly: $m_{\text{anomalistic}} = 27.56$ d
- solar anomaly: 1 yr $= 365.25$ d
- nodal motion: 1 revolution $= 18.60$ yr; $\overline{m}_{\text{draconitic}} = 27.21$ d
- time between successive lunations $\equiv m_{\text{synodic}}$; $\overline{m}_{\text{synodic}} = 29.53$ d
- 1 Saros $\equiv$ 223 synodic m $\approx 239 m_{\text{anomalistic}} \approx 242 \overline{m}_{\text{draconitic}}$
  1 Saros $\approx 6585\frac{1}{3}$ d $\approx$ 18 yr $+$ 11 d
- computational astronomy (System A): 6247 synodic m $= 6695 m_{\text{anomalistic}}$

VAT 209 + MMA 86.11.405

49/48 BC Babylon



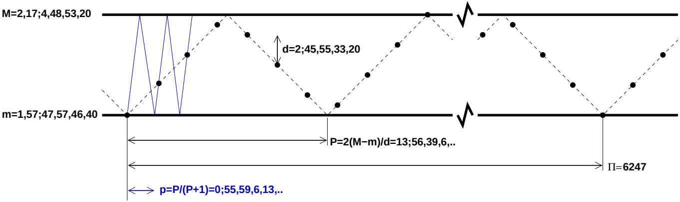
	T		Φ	B		C	E	Ψ′	F
1	4,22	12.2	2,5;59,4,26,40	22;41,15	Ari	3,8;27,30	-5,54;29,15 ↓	-1,51;33,45	13;8,23,26,15
2	4,23	1	2,3;13,8,53,20	20;48,45	Tau	3,24;19,30	-6,30;45,3 ↑	-1,28;51,1	12;26,23,26,15
3		2	2,0;27,13,20	18;56,15	Gem	3,33;11,30	-4,31;59,21 ↑	-49;15,47	11;44,23,26,15
4		3	1,57;54,37,46,40	17;3,45	Can	3,35;3,30	-2,33;13,39 ↑	-9;40,33	11;5,45,56,15
5		4	2,0;40,33,20	15;11,15	Leo	3,29;55,30	1,15;4,6 ↑	29;54,41	11;47,45,56,15
6		5	2,3;26,28,53,20	13;	Vir	3,17;46,40	3,48;22,45 ↑	1,9;31,35	12;29,45,56,15
7		6	2,6;12,24,26,40	13;20	Lib	2,57;46,40	5,54;38,27 ↑	1,51;36,49	13;11,45,56,15
8		7	2,8;58,20	13;20	Sco	2,38;40	6,23;5,51 ↓	1,26;17,57	13;53,45,56,15
9		8	2,11;44,15,33,20	13;20	Sag	2,27;33,20	4,16;50,9 ↓	44;12,43	14;35,45,56,15
10		9	2,14;30,11,6,40	13;20	Cap	2,24;26,40	1,57;8,54 ↓	2;7,29	15;17,45,56,15
11		10	2,16;53,31,6,40	13;20	Aqu	2,29;20	-2,15;22,30 ↓	-39;57,45	15;54,2,48,45
12		11	2,14;7,35,33,20	13;20	Pis	2,42;13,20	-4,25;56,57 ↓	-1,22;2,59	15;12,2,48,45
13		12	2,11;21,40	12;18,45	Ari	3,1;32,30	-6,28;7,39 ↓	-1,57;13,27	14;30,2,48,45

	G	J	C′	K	M			NA_1		
1	3,37;1,58,31,6,40	-52;7,1,30	-9;25,45	2,35;29	12.2	29	3,32;57	1	1	19;50
2	4,2;50,37,2,13,20	-57;3,45	-7;56	2,57;50	1	29	35;7	2	30	13;30 xxx
3	4,28;39,15,33,20	-57;3,45	-4;26	3,23;54	2	29	3,11;13	3	1	12;50
4	4,52;51,47,24,26,40	-57;3,45	-0;56	4,54;52	3	29	4,16;21	4	1	19;50
5	4,49;17,54,4,26,40	-57;3,45	2;34	3,52;17	4	28	24;4	5	1	20;30 30 8;29 xx
6	4,23;48,53,20	-56;25,42,30	6;4,25	3,33;27	5	28	2,50;37	6	30	13;20
7	3,58;0,14,48,53,20	0	10	4,8	6	x	4,42;37	7	30	x;50
8	3,32;11,36,17,46,40	0	9;33,20	3,41;44	7	29	1,0;53	8	1	15;10 x
9	3,6;22,57,46,40	0	5;33,20	3,11;56	8	29	3,48;57	9	1	22;30 30 x
10	2,43;32,2,13,20	0	1;33,20	2,45;5	9	28	1,3;52	10	30	16;40
11	2,40	0	-2;26,40	2,37;33	10	[x]	4,26;19	11	30	10 x
12	2,40	0	-6;26,40	2,33;33	11	29	1,52;46	12	1	20;10 x
13	2,47;35	-31;4,2,30	-9;39,35	2,6;51	12	29	5,45;55	1	30	14 [x]

columns T, Φ, F

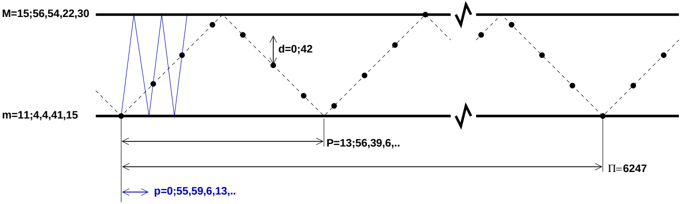
T = date [year SE, month]

Φ parametrises lunar anomaly



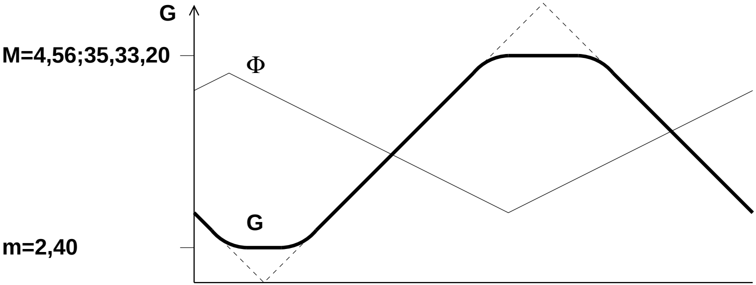
Φ = *duration of Saros − 6585 days under assumption of constant solar velocity* [°]

F = lunar velocity along ecliptic [$^\circ\ \mathrm{d}^{-1}$]



column G

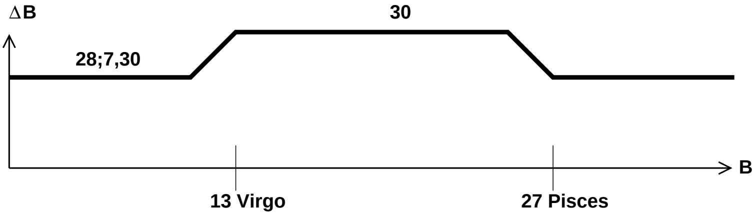
G = synodic month − 29 d under assumption of constant solar velocity [°]



column B

B = ecliptical longitude of Moon (and Sun) [zodiacal sign; °] under assumption of constant lunar velocity

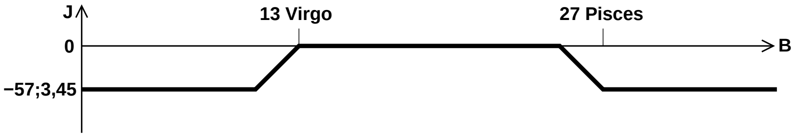
$$B_i = B_{i-1} + \Delta B(B_{i-1})$$



column J

J = correction to synodic month due to variable solar velocity [°]

$$J_i = J(B_i)$$

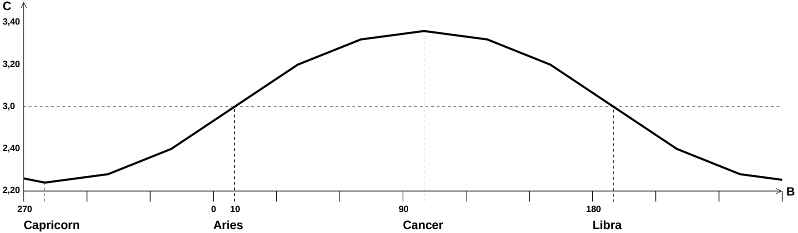


$G + J$ = synodic month - 29 d [°]

columns C,C'

C = length of daylight [°]

$$C_i = C(B_i)$$



C' = correction to time of conjunction due to changing length of daylight [°]

$$C'_i = -(C_i - C_{i-1})/2$$

columns K,M

K = change of time of conjunction w.r.t. sunset [°].

$$K_i = G_i + J_i + C_i'$$

M = time of conjunction w.r.t. sunset [° before sunset]

$$M_i = M_{i-1} - K_i$$

if $K_i > M_{i-1}$ add 6,0° to M_{i-1} and 1 day to date

if $M_i > 6{,}0°$ subtract 6,0° from M_i and 1 day from date

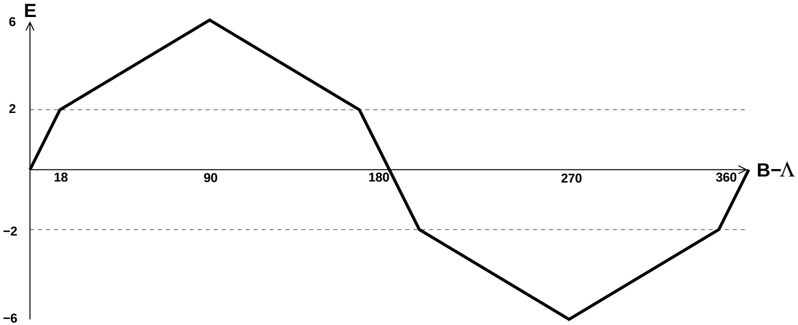
column E

E = lunar latitude [°]

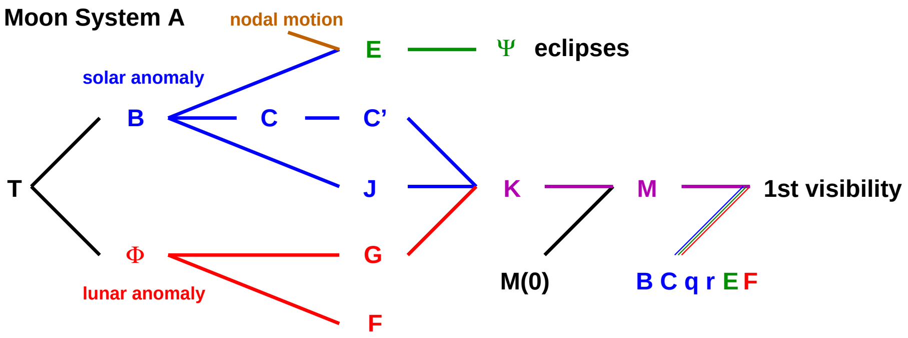
$$E_i = E(B_i - \Lambda_i)$$

Λ = longitude of ascending node [°]

$$\Lambda_i = \Lambda_{i-1}\text{-}1;33,55,30°$$



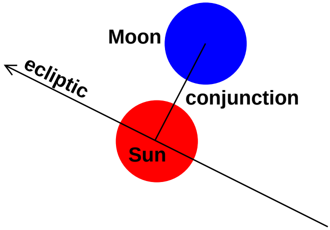
Moon System A: flow chart



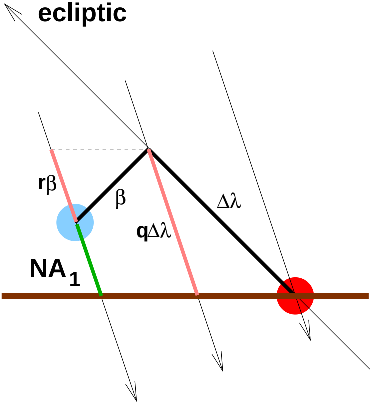
1st visibility

NA_1 = time between sunset after conjunction and moonset [°]

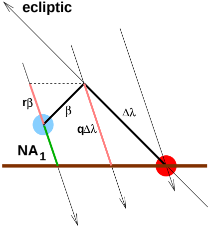
conjunction

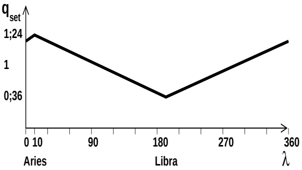


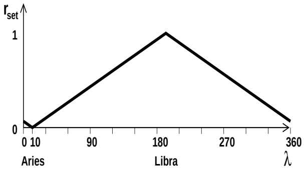
sunset after conjunction



1st visibility





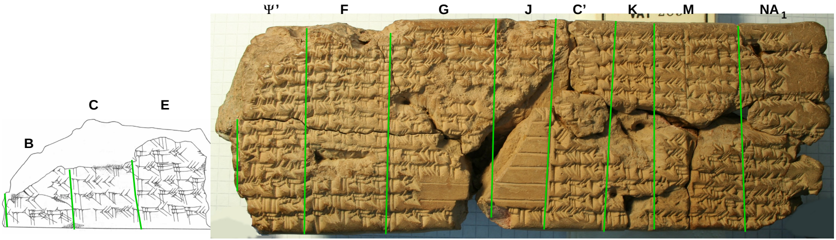


1. M = time from conjunction to sunset [°]
2. lunar longitude at sunset: $\lambda_{\text{moon}} = B + F \cdot M$
   solar longitude at sunset: $\lambda_{\text{sun}} = B + 1 \cdot M$
3. lunar elongation at sunset: $\Delta\lambda = \lambda_{\text{moon}} - \lambda_{\text{sun}}$
4. contribution to NA_1 due to elongation: $q_{\text{set}}(\lambda_{\text{sun}}) \cdot \Delta\lambda$
5. lunar latitude at sunset: $\beta = E \pm 0;4\, F \cdot M$
6. contribution to NA_1 due to lunar latitude: $r_{\text{set}}(\lambda_{\text{sun}}) \cdot \beta$
7. $NA_1 = q_{\text{set}} \cdot \Delta\lambda \pm r_{\text{set}} \cdot \beta$
8. if NA_1 insufficient repeat 1-7 for next sunset (add 6,0° to M)

Moon System A: synodic table

VAT 209 + MMA 86.11.405

49/48 BC Babylon



	T		Φ	B		C	E	Ψ′	F	G	J	C′	K	M			NA$_1$		
1	4,22	12.2	2,5;59,4,26,40	22;41,15	Ari	3,8;27,30	-5,54;29,15 ↓	-1,51;33,45	13;8,23,26,15	3,37;1,58,31,6,40	-52;7,1,30	-9;25,45	2,35;29	12.2	29	3,32;57	1	1	19;50
2	4,23	1	2,3;13,8,53,20	20;48,45	Tau	3,24;19,30	-6,30;45,3 ↑	-1,28;51,1	12;26,23,26,15	4,2;50,37,2,13,20	-57;3,45	-7;56	2,57;50	1	29	35;7	2	30	13;30 xxx
3		2	2,0;27,13,20	18;56,15	Gem	3,33;11,30	-4,31;59,21 ↑	-49;15,47	11;44,23,26,15	4,28;39,15,33,20	-57;3,45	-4;26	3,23;54	2	29	3,11;13	3	1	12;50
4		3	1,57;54,37,46,40	17;3,45	Can	3,35;3,30	-2,33;13,39 ↑	-9;40,33	11;5,45,56,15	4,52;51,47,24,26,40	-57;3,45	-0;56	4,54;52	3	29	4,16;21	4	1	19;50
5		4	2,0;40,33,20	15;11,15	Leo	3,29;55,30	1,15;4,6 ↑	29;54,41	11;47,45,56,15	4,49;17,54,4,26,40	-57;3,45	2;34	3,52;17	4	28	24;4	5	1	20;30 30 8;29 xx
6		5	2,3;26,28,53,20	13;	Vir	3,17;46,40	3,48;22,45 ↑	1,9;31,35	12;29,45,56,15	4,23;48,53,20	-56;25,42,30	6;4,25	3,33;27	5	28	2,50;37	6	30	13;20
7		6	2,6;12,24,26,40	13;20	Lib	2,57;46,40	5,54;38,27 ↑	1,51;36,49	13;11,45,56,15	3,58;0,14,48,53,20	0	10	4,8	6	x	4,42;37	7	30	x;50
8		7	2,8;58,20	13;20	Sco	2,38;40	6,23;5,51 ↓	1,26;17,57	13;53,45,56,15	3,32;11,36,17,46,40	0	9;33,20	3,41;44	7	29	1,0;53	8	1	15;10 x
9		8	2,11;44,15,33,20	13;20	Sag	2,27;33,20	4,16;50,9 ↓	44;12,43	14;35,45,56,15	3,6;22,57,46,40	0	5;33,20	3,11;56	8	29	3,48;57	9	1	22;30 30 x
10		9	2,14;30,11,6,40	13;20	Cap	2,24;26,40	1,57;8,54 ↓	2;7,29	15;17,45,56,15	2,43;32,2,13,20	0	1;33,20	2,45;5	9	28	1,3;52	10	30	16;40
11		10	2,16;53,31,6,40	13;20	Aqu	2,29;20	-2,15;22,30 ↓	-39;57,45	15;54,2,48,45	2,40	0	-2;26,40	2,37;33	10	[x]	4,26;19	11	30	10 x
12		11	2,14;7,35,33,20	13;20	Pis	2,42;13,20	-4,25;56,57 ↓	-1,22;2,59	15;12,2,48,45	2,40	0	-6;26,40	2,33;33	11	29	1,52;46	12	1	20;10 x
13		12	2,11;21,40	12;18,45	Ari	3,1;32,30	-6,28;7,39 ↓	-1,57;13,27	14;30,2,48,45	2,47;35	-31;4,2,30	-9;39,35	2,6;51	12	29	5,45;55	1	30	14 [x]

who were the Babylonian astronomers?

colofons

AO 6476 + U 104 (Uruk 194 BC)

'Tablet of Šamaš-ēṭir, son of Ina-qibīt-Anu, son of Šipqat-Anu, descendant of Ekur-zākir... Hand of Anu-aba-utēr, son of Anu-bēlšunu, descendant of Sin-lēqi-unninni, lamentation priest of Anu and Antu, from Uruk.'

pioneers

'[...computed tab]le of Nabû-rēmannu...'

VAT 209 + MMA 86.11.405 (Babylon 48 BC)

- Nabû-rēmannu = author of System A? (= Strabo's Naburianos)
- Kidinnu = author of System B? (= Strabo's Kidenas)

professional titles

- lamentation priest, divination priest
- 'scribe of *When Anu and Enlil*' = astronomer/astrologer, 'Sternkundiger'

who were the Babylonian astronomers?

duties

BM 35559 (protocol of Esagila temple council, Babylon 118 BC)

‘We have witnessed ourselves that he is capable of carrying out the observations... We shall pay him yearly in silver for carrying out the observations and delivering the tables and the measurements...’

clan affiliation

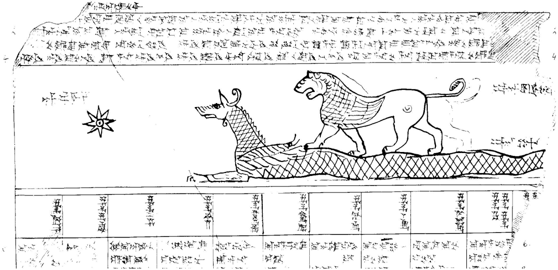
Sîn-lēqi-unninni

Nidinti-Anu
|
Anu-bēlšunu — SE 82-143 = 229-168 vC
| — Nidinti-Anu
| — Anu-aba-utēr

Nidinti-Anu
|
Anu-balāssu-iqbi

Anu-bēlšunu

astrological text VAT 7847 (Uruk)



'Tablet of Anu-bēlšunu, lamentation priest of Anu .....'

stamp seal MLC 2170 (Uruk)

'Seal of Anu-bēlšunu'

horoscope NCBT 1231 (Uruk)

In the year 63 SE, month 10, night of day 2 (30/12/249 BC) Anu-bēlšunu was born. On that day the Sun was in 9;30 Capricorn, the Moon in 12 Aquarius: his days will be long.'

summary and outlook

Late Babylonian computational astronomy

- end point of long preoccupation with celestial phenomena
- quite sophisticated predictive computational schemes
  - introduction of zodiak
  - principle of decomposition
- no formulation of principles, assumptions
- no evidence of 'physical', cosmological concepts
- development of abstract mathematical representation

open questions

- origin (e.g. Φ)
- relation to other astronomical text groups
- goal; organisation