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Eclipse Prediction in Mesopotamia

JOHN M. STEELE

I have already discussed how the Assyrians seem to have realized that eclipse possibilities were separated by six or occasionally five month intervals. To reliably predict eclipses, the Babylonian astronomers needed to formulate a scheme to determine when these five month intervals were required. Commencing in the middle of the eighth century BC it seems that a more or less complete record of observed lunar eclipses was available to the Babylonian astronomers. Britton has shown that by a fairly basic analysis of this observational record, simple schemes for the arrangement of the five and six month intervals could be identified.³⁶ The most important of these is the Saros of 223 months. Within each Saros cycle there are 38 eclipse possibilities, 33 of which are separated by six month intervals, and the remaining 5 by five month intervals. Using the simple rule that these should be distributed as evenly as possible we get the following arrangement: if the first eclipse in a Saros cycle comes five months after the preceding eclipse possibility, then it will be followed by seven eclipses (nos. 2–8) each of which is

³⁵ J. M. Steele and F. R. Stephenson, “Lunar Eclipse Times Predicted by the Babylonians,” *Journal for the History of Astronomy*, 28 (1997) 119–131 and J. M. Steele, “Solar Eclipse Times Predicted by the Babylonians,” *Journal for the History of Astronomy*, 28 (1997) 131–139. In the first of these papers I speculated that one motivation for predicting the time of the beginning of the eclipse, rather than the moment of syzygy, was that if the prediction was to be used for religious purposes then it seems likely that the moment when the eclipse would begin would be the most useful time to predict. This has now been confirmed by the description of an eclipse ritual on BM 134761 which explains that the period of ritual lamentation during an eclipse begins at the moment of first contact and continues until the middle of the eclipse. See D. Brown and M. Linssen, “BM 134761 = 1965-10-14, 1 and the Hellenistic Period Eclipse Ritual from Uruk,” *Revue d’Assyriologie et d’Archéologie Orientale* (forthcoming).

³⁶ J. P. Britton, “An Early Function for Eclipse Magnitude in Babylonian Astronomy,” *Centaurus* 32 (1989), 1–52. See also O. Neugebauer, *A History of Ancient Mathematical Astronomy* (Springer-Verlag, Berlin, 1975), 504–505.

six months after the preceding eclipse, then an eclipse (no. 9) at five months, six more (nos. 10–15) at six months, another (no. 16) at five months, seven (nos. 17–23) at six months, another (no. 24) at five months, six at six months (nos. 25–30), one more at five months (no. 31), and finally seven (nos. 32–38) at six months. Thus the 38 eclipse possibilities are divided into five groups, each of which begins with an eclipse possibility five months after the preceding eclipse, containing eight, seven, eight, seven, and eight eclipses respectively. This is often written as 8-7-8-7-8. Of course, the definition of the beginning of the Saros period is arbitrary, and the distribution could equally well be 7-8-7-8-8, 8-7-8-8-7, 7-8-8-7-8 or 8-8-7-8-7. The last distribution is that found by Aaboe from a theoretical analysis of eclipse possibilities equally spaced in longitude.³⁷ That such arrangements were recognized by the Babylonian astronomers is proven by a number of tablets such as the “Saros Canon” (LBAT 1428) and the Eclipse Texts LBAT *1414, LBAT 1415 + 1416 + 1417, and LBAT *1419 which are all laid out in a format based upon this distribution of eclipse possibilities. These texts were all written sometime after the middle of the fourth century BC but refer to dates stretching back to –730. However, the preserved part of the text LBAT *1420 contains eclipse observations and predictions from –603 to –575 which also follow the 8-7-8-7-8 arrangement of eclipse possibilities, and this text was probably compiled not long after its final entry in –575, thus indicating that the Saros was in use by this period. Temple documents describing the ritual performed in anticipation of an eclipse that did not occur in the eighth year of Cyrus also imply that the Saros was in use by at least the sixth century BC.³⁸

Once the 8-7-8-7-8 scheme had been identified, the next problem facing the Babylonian astronomers was to decide when to begin the scheme (in other words, which eclipse possibility was to be defined as no. 1). Evidence for their solution to this problem comes from the records themselves. The texts LBAT *1414, LBAT 1415 + 1416 + 1417, and LBAT *1419 all appear to come from a large compilation of eclipse records that probably originally stretched from –746 to –314.³⁹ Running through these texts is the expected 8-7-8-7-8 grouping of eclipses, and where an eclipse is predicted at a five month interval, the record will explicitly state 5 ITU “5 months.” Unfortunately, however, these texts are somewhat fragmentary and so do not fully define the placing of the five month intervals. Following a suggestion by Christopher Walker, therefore, I have attempted to reconstruct this compilation by supplementing the records contained in it with those preserved in other NMAT sources.⁴⁰ The results are shown in columns 1–24 of Table 2.

³⁷ A. Aaboe, “Remarks on the Theoretical Treatment of Eclipses in Antiquity,” *Journal for the History of Astronomy* 3 (1972), 105–118.

³⁸ P.-A. Beaulieu and J. P. Britton, “Rituals for an Eclipse Possibility in the 8th Year of Cyrus,” *Journal of Cuneiform Studies* 46 (1994), 73–86.

³⁹ C. B. F. Walker, “Achaemenid Chronology and the Babylonian Sources,” in J. Curtis (ed.), *Mesopotamia and Iran in the Persian Period: Conquest and Imperialism 539–331 BC* (British Museum Press, London, 1997), 17–25. A full discussion of the structure and layout of all the Eclipse Texts is given in my appendix to A. J. Sachs and H. Hunger, *Astronomical Diaries and Related Texts from Babylon, Volume V* (Österreichischen Akademie der Wissenschaften, Vienna, forthcoming).

⁴⁰ These dates have been taken from the list of eclipse records in J. M. Steele, *Observations and Predictions of Eclipse Times by Early Astronomers* (forthcoming), Appendix 1.

In this table, dates of eclipses which were (at least partly) visible in Babylon are indicated in bold.⁴¹ There is no distinction between dates of eclipses not visible because they occurred during the daytime, and those dates when there was no umbral eclipse. Dates of eclipse possibilities for which we have a record in an NMAT source are underlined, and those where we have an explicit statement of the five month interval are in italics (a number of other five month intervals are implicitly determined by the dates of the recorded eclipses). The layout of the five month intervals between groups of eclipses is illustrated by the empty rows in the table.⁴² It should be noted that this distribution of the eclipse possibilities comes naturally from the observable eclipses in the very first column of the table. If one assumes that the first eclipse in a group is the first eclipse that is visible after an interval of $6n - 1$ months from the preceding visible eclipse, and that the two groups containing only seven eclipse possibilities do not come immediately after one another, then there is no option but to choose the distribution given here.

Interestingly, there are no eclipse records between -746 and -314 that contradict this distribution of eclipse possibilities. Indeed, between -746 and -340 the scheme correctly predicts every eclipse that was visible in Babylon. On -339 September 29 and again on -321 October 20 a lunar eclipse occurred which was not predicted by this scheme. Instead, eclipses were predicted one month earlier. These are noted by an asterisk after the predicted date in the table. Both eclipses, however, had only very small magnitudes (0.10 and 0.13 respectively), and may not have been noticed by the Babylonian astronomers.⁴³ It would therefore seem that this scheme was used throughout the period from -746 to -314. Furthermore, extending the scheme for a further three cycles down to at least -278, there is still no disagreement between this scheme and the records of observed and predicted eclipses on the NMAT, although two more unpredicted eclipses (on -285 October 3 and -281 January 26) may have been visible. However, the evidence suggests that the scheme may have continued being used until at least -278.

⁴¹ In this and the following tables, dates of full and new moons have been taken from H. H. Goldstine, *New and Full Moons 1001 BC to AD 1651* (American Philosophical Society, Philadelphia, 1973).

⁴² For columns 8 and 9 the tablet LBAT *1420 fully determines the layout of the table, but the important point is that by reconstructing the whole table as described above, we can see that this same layout extends beyond these two columns.

⁴³ The Diaries for those months are unfortunately not preserved, so we cannot be sure whether these two eclipses were observed or not.

Table 2. Distribution of lunar eclipse possibilities over the Late Babylonian period

| | 1 | 2 | 3 | 4 | 5 | 6 |
|----|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 1 | <u>-746 Feb 6</u> | -728 Feb 17 | -710 Feb 27 | -692 Mar 10 | -674 Mar 21 | -656 Mar 31 |
| 2 | <u>-746 Aug 2</u> | -728 Aug 12 | -710 Aug 23 | -692 Sep 3 | -674 Sep 14 | -656 Sep 24 |
| 3 | <u>-745 Jan 26</u> | -727 Feb 5 | -709 Feb 16 | -691 Feb 27 | -673 Mar 10 | -655 Mar 20 |
| 4 | <u>-745 Jul 22</u> | -727 Aug 2 | -709 Aug 13 | -691 Aug 23 | -673 Sep 4 | -655 Sep 14 |
| 5 | <u>-744 Jan 15</u> | -726 Jan 25 | -708 Feb 6 | -690 Feb 16 | -672 Feb 27 | -654 Mar 10 |
| 6 | <u>-744 Jul 11</u> | -726 Jul 22 | -708 Aug 1 | -690 Aug 12 | -672 Aug 23 | -654 Sep 3 |
| 7 | -743 Jan 3 | -725 Jan 15 | -707 Jan 25 | -689 Feb 6 | -671 Feb 16 | -653 Feb 27 |
| 8 | -743 Jun 30 | -725 Jul 11 | -707 Jul 21 | -689 Aug 2 | -671 Aug 12 | -653 Aug 23 |
| 9 | -743 Nov 25 | -725 Dec 6 | -707 Dec 16 | -689 Dec 28 | -670 Jan 7 | -652 Jan 19 |
| 10 | -742 May 20 | -724 May 31 | -706 Jun 11 | -688 Jun 21 | -670 Jul 2 | -652 Jul 13 |
| 11 | -742 Nov 14 | -724 Nov 25 | -706 Dec 6 | -688 Dec 16 | -670 Dec 28 | -651 Jan 7 |
| 12 | -741 May 10 | -723 May 20 | -705 May 31 | -687 Jun 11 | -669 Jun 22 | <u>-651 Jul 2</u> |
| 13 | -741 Nov 3 | -723 Nov 14 | -705 Nov 25 | -687 Dec 5 | -669 Dec 17 | <u>-651 Dec 27</u> |
| 14 | -740 Apr 28 | -722 May 10 | -704 May 20 | -686 May 31 | -668 Jun 11 | -650 Jun 22 |
| 15 | -740 Oct 22 | -722 Nov 3 | -704 Nov 13 | -686 Nov 24 | -668 Dec 5 | -650 Dec 16 |
| 16 | -739 Mar 20 | -721 Mar 31 | -703 Apr 10 | -685 Apr 22 | <u>-667 May 2</u> | <u>-649 May 13</u> |
| 17 | -739 Sep 12 | -721 Sep 23 | -703 Oct 3 | <u>-685 Oct 15</u> | <u>-667 Oct 25</u> | <u>-649 Nov 6</u> |
| 18 | -738 Mar 9 | -720 Mar 19 | -702 Mar 31 | -684 Apr 10 | -666 Apr 21 | -648 May 2 |
| 19 | -738 Sep 1 | -720 Sep 12 | -702 Sep 23 | -684 Oct 3 | -666 Oct 15 | -648 Oct 25 |
| 20 | -737 Feb 26 | -719 Mar 9 | <u>-701 Mar 20</u> | <u>-683 Mar 30</u> | -665 Apr 10 | -647 Apr 21 |
| 21 | -737 Aug 22 | -719 Sep 1 | -701 Sep 13 | -683 Sep 23 | -665 Oct 4 | -647 Oct 15 |
| 22 | -736 Feb 15 | -718 Feb 26 | -700 Mar 8 | -682 Mar 19 | -664 Mar 29 | -646 Apr 10 |
| 23 | -736 Aug 11 | -718 Aug 22 | -700 Sep 1 | -682 Sep 13 | -664 Sep 23 | -646 Oct 4 |
| 24 | -735 Jan 5 | -717 Jan 16 | -699 Jan 27 | -681 Feb 7 | -663 Feb 17 | -645 Mar 1 |
| 25 | -735 Jul 1 | -717 Jul 13 | -699 Jul 23 | -681 Aug 3 | -663 Aug 14 | -645 Aug 25 |
| 26 | -735 Dec 25 | -716 Jan 6 | -698 Jan 16 | -680 Jan 28 | -662 Feb 7 | -644 Feb 18 |
| 27 | -734 Jun 21 | -716 Jul 1 | -698 Jul 12 | -680 Jul 22 | -662 Aug 3 | -644 Aug 13 |
| 28 | -734 Dec 15 | -716 Dec 25 | -697 Jan 6 | -679 Jan 16 | -661 Jan 28 | -643 Feb 7 |
| 29 | -733 Jun 10 | -715 Jun 20 | -697 Jul 1 | -679 Jul 11 | -661 Jul 23 | -643 Aug 2 |
| 30 | -733 Dec 5 | -715 Dec 15 | -697 Dec 26 | -678 Jan 6 | -660 Jan 17 | -642 Jan 27 |
| 31 | -732 Apr 30 | -714 May 11 | -696 May 21 | -678 Jun 2 | -660 Jun 12 | -642 Jun 23 |
| 32 | -732 Oct 24 | -714 Nov 4 | -696 Nov 15 | -678 Nov 26 | -660 Dec 6 | -642 Dec 18 |
| 33 | -731 Apr 19 | -713 May 1 | -695 May 11 | -677 May 22 | -659 Jun 2 | -641 Jun 13 |
| 34 | -731 Oct 13 | -713 Oct 24 | -695 Nov 4 | -677 Nov 15 | -659 Nov 25 | -641 Dec 7 |
| 35 | -730 Apr 9 | -712 Apr 19 | <u>-694 May 1</u> | <u>-676 May 11</u> | -658 May 22 | -640 Jun 2 |
| 36 | -730 Oct 2 | -712 Oct 13 | -694 Oct 24 | -676 Nov 3 | -658 Nov 15 | -640 Nov 25 |
| 37 | -729 Mar 30 | -711 Apr 9 | -693 Apr 20 | -675 Apr 30 | -657 May 12 | -639 May 22 |
| 38 | -729 Sep 22 | -711 Oct 2 | -693 Oct 13 | -675 Oct 24 | -657 Nov 4 | -639 Nov 15 |

Table 2. (Cont.)

| | 7 | 8 | 9 | 10 | 11 | 12 |
|----|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 1 | -638 Apr 11 | -620 Apr 22 | <u>-602 May 3</u> | -584 May 13 | -566 May 25 | -548 Jun 4 |
| 2 | -638 Oct 6 | -620 Oct 16 | <u>-602 Oct 26</u> | -584 Nov 7 | -566 Nov 18 | -548 Nov 29 |
| 3 | -637 Apr 1 | -619 Apr 11 | <u>-601 Apr 22</u> | -583 May 2 | -565 May 14 | -547 May 24 |
| 4 | -637 Sep 25 | -619 Oct 6 | <u>-601 Oct 17</u> | -583 Oct 27 | -565 Nov 8 | -547 Nov 18 |
| 5 | -636 Mar 20 | -618 Mar 31 | <u>-600 Apr 11</u> | -582 Apr 22 | -564 May 2 | -546 May 14 |
| 6 | -636 Sep 13 | -618 Sep 25 | <u>-600 Oct 5</u> | -582 Oct 16 | -564 Oct 27 | -546 Nov 7 |
| 7 | -635 Mar 10 | -617 Mar 21 | <u>-599 Mar 31</u> | -581 Apr 12 | -563 Apr 22 | -545 May 3 |
| 8 | -635 Sep 2 | -617 Sep 14 | <u>-599 Sep 24</u> | -581 Oct 5 | -563 Oct 16 | -545 Oct 27 |
| 9 | -634 Jan 29 | -616 Feb 9 | <u>-598 Feb 20</u> | -580 Mar 2 | <u>-562 Mar 13</u> | -544 Mar 24 |
| 10 | -634 Jul 24 | -616 Aug 3 | <u>-598 Aug 15</u> | -580 Aug 25 | <u>-562 Sep 5</u> | -544 Sep 16 |
| 11 | -633 Jan 18 | -615 Jan 29 | -597 Feb 9 | -579 Feb 19 | <u>-561 Mar 3</u> | -543 Mar 13 |
| 12 | -633 Jul 14 | -615 Jul 24 | -579 Aug 4 | <u>-579 Aug 15</u> | -561 Aug 26 | -543 Sep 5 |
| 13 | -632 Jan 7 | -614 Jan 18 | -596 Jan 29 | <u>-578 Feb 8</u> | -560 Feb 20 | -542 Mar 2 |
| 14 | -632 Jul 2 | -614 Jul 14 | -595 Jul 24 | <u>-578 Aug 4</u> | <u>-560 Aug 15</u> | -542 Aug 26 |
| 15 | -632 Dec 26 | -613 Jan 7 | -595 Jan 17 | <u>-577 Jan 28</u> | -559 Feb 8 | -541 Feb 19 |
| 16 | <u>-631 May 24</u> | -613 Jun 4 | -595 Jun 14 | <u>-577 Jun 25</u> | -559 Jul 9 | -541 Jul 17 |
| 17 | -631 Nov 16 | -613 Nov 27 | -595 Dec 8 | <u>-577 Dec 19</u> | -559 Dec 29 | -540 Jan 10 |
| 18 | -630 May 13 | -612 May 23 | -594 Jun 3 | <u>-576 Jun 14</u> | -558 Jun 25 | -540 Jul 5 |
| 19 | -630 Nov 5 | -612 Nov 16 | <u>-594 Nov 27</u> | <u>-576 Dec 8</u> | -558 Dec 19 | -540 Dec 29 |
| 20 | -629 May 2 | -611 May 12 | <u>-593 May 23</u> | <u>-575 Jun 3</u> | -557 Jun 14 | -539 Jun 24 |
| 21 | -629 Oct 26 | <u>-611 Nov 5</u> | <u>-593 Nov 17</u> | -575 Nov 27 | -557 Dec 9 | -539 Dec 19 |
| 22 | -628 Apr 20 | -610 May 1 | <u>-592 May 12</u> | -574 May 23 | -556 Jun 2 | -538 Jun 13 |
| 23 | -628 Oct 15 | -610 Oct 26 | <u>-592 Nov 5</u> | -574 Nov 17 | -556 Nov 27 | -538 Dec 8 |
| 24 | -627 Mar 11 | -609 Mar 22 | <u>-591 Apr 2</u> | -573 Apr 13 | -555 Apr 23 | -537 May 5 |
| 25 | -627 Sep 4 | <u>-609 Sep 16</u> | <u>-591 Sep 26</u> | -573 Oct 7 | -555 Oct 17 | -537 Oct 29 |
| 26 | -626 Mar 1 | -608 Mar 11 | <u>-590 Mar 22</u> | <u>-572 Apr 2</u> | -554 Apr 13 | <u>-536 Apr 23</u> |
| 27 | -626 Aug 24 | -608 Sep 4 | -590 Sep 15 | <u>-572 Sep 25</u> | <u>-554 Oct 6</u> | <u>-536 Oct 17</u> |
| 28 | -625 Feb 18 | <u>-607 Mar 1</u> | <u>-589 Mar 12</u> | <u>-571 Mar 22</u> | <u>-553 Apr 3</u> | -535 Apr 13 |
| 29 | -625 Aug 13 | -607 Aug 24 | <u>-589 Sep 4</u> | <u>-571 Sep 14</u> | <u>-553 Sep 26</u> | -535 Oct 6 |
| 30 | -624 Feb 8 | -606 Feb 18 | <u>-588 Feb 29</u> | -570 Mar 12 | -552 Mar 22 | -534 Apr 2 |
| 31 | -624 Jul 4 | -606 Jul 15 | <u>-588 Jul 25</u> | -570 Aug 5 | -552 Aug 16 | -534 Aug 27 |
| 32 | -624 Dec 28 | -605 Jan 8 | <u>-587 Jan 19</u> | -569 Jan 30 | <u>-551 Feb 9</u> | -533 Feb 21 |
| 33 | -623 Jun 23 | -605 Jul 5 | <u>-587 Jul 15</u> | -569 Jul 26 | <u>-551 Aug 6</u> | -533 Aug 17 |
| 34 | -623 Dec 17 | -605 Dec 28 | <u>-586 Jan 8</u> | -568 Jan 19 | -550 Jan 29 | -532 Feb 10 |
| 35 | -622 Jun 13 | -604 Jun 23 | <u>-586 Jul 4</u> | -568 Jul 15 | -550 Jul 26 | -532 Aug 5 |
| 36 | -622 Dec 6 | -604 Dec 17 | -586 Dec 28 | -567 Jan 7 | -549 Jan 19 | -531 Jan 29 |
| 37 | -621 Jun 2 | <u>-603 Jun 13</u> | -585 Jun 24 | <u>-567 Jul 4</u> | <u>-549 Jul 15</u> | -531 Jul 26 |
| 38 | -621 Nov 26 | <u>-603 Dec 6</u> | -585 Dec 18 | -567 Dec 28 | -548 Jan 8 | -530 Jan 19 |

Table 2. (Cont.)

| | 13 | 14 | 15 | 16 | 17 | 18 |
|----|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| 1 | -530 Jun 15 | -512 Jun 25 | -494 Jul 7 | -476 Jul 17 | -458 Jul 28 | -440 Aug 7 |
| 2 | -530 Dec 10 | -512 Dec 20 | -493 Jan 1 | -475 Jan 11 | -457 Jan 22 | -439 Feb 2 |
| 3 | -529 Jun 4 | -511 Jun 15 | -493 Jun 26 | -475 Jul 6 | -457 Jul 17 | -439 Jul 28 |
| 4 | -529 Nov 29 | -511 Dec 10 | -493 Dec 21 | -475 Dec 31 | -456 Jan 12 | -438 Jan 22 |
| 5 | -528 May 24 | -510 Jun 4 | -492 Jun 14 | -474 Jun 26 | -456 Jul 6 | -438 Jul 17 |
| 6 | -528 Nov 17 | -510 Nov 29 | -492 Dec 9 | -474 Dec 20 | -456 Dec 31 | -437 Jan 11 |
| 7 | -527 May 14 | -509 May 25 | -491 Jun 4 | -473 Jun 15 | -455 Jun 26 | -437 Jul 7 |
| 8 | <u>-527 Nov 6</u> | -509 Nov 18 | -491 Nov 28 | -473 Dec 9 | -455 Dec 20 | -437 Dec 31 |
| 9 | <u>-526 Apr 4</u> | -508 Apr 14 | -490 Apr 25 | -472 May 6 | -454 May 17 | -436 May 27 |
| 10 | <u>-526 Sep 27</u> | -508 Oct 7 | -490 Oct 19 | -472 Oct 29 | -454 Nov 9 | -436 Nov 20 |
| 11 | <u>-525 Mar 24</u> | -507 Apr 3 | -489 Apr 15 | -471 Apr 25 | -453 May 6 | -435 May 17 |
| 12 | -525 Sep 17 | -507 Sep 27 | -489 Oct 8 | -471 Oct 19 | -453 Oct 30 | -435 Nov 9 |
| 13 | -524 Mar 12 | -506 Mar 24 | -488 Apr 3 | -470 Apr 14 | -452 Apr 24 | -434 May 6 |
| 14 | -524 Sep 5 | -506 Sep 17 | -488 Sep 27 | -470 Oct 8 | -452 Oct 19 | -434 Oct 30 |
| 15 | -523 Mar 1 | -505 Mar 13 | -487 Mar 23 | -469 Apr 3 | -451 Apr 13 | -433 Apr 25 |
| 16 | -523 Jul 27 | -505 Aug 8 | -487 Aug 18 | -469 Aug 29 | -451 Sep 9 | -433 Sep 20 |
| 17 | -522 Jan 20 | -504 Jan 31 | -486 Feb 11 | -468 Feb 22 | -450 Mar 4 | -432 Mar 15 |
| 18 | -522 Jul 16 | -504 Jul 27 | -486 Aug 7 | -468 Aug 17 | -450 Aug 29 | -432 Sep 8 |
| 19 | -521 Jan 10 | -503 Jan 20 | -485 Jan 31 | -467 Feb 11 | -449 Feb 22 | -431 Mar 4 |
| 20 | -521 Jul 5 | -503 Jul 16 | -485 Jul 27 | -467 Aug 6 | -449 Aug 18 | -431 Aug 28 |
| 21 | -521 Dec 30 | -502 Jan 10 | -484 Jan 21 | -466 Jan 31 | -448 Feb 12 | -430 Feb 22 |
| 22 | -520 Jun 24 | -502 Jul 5 | -484 Jul 15 | -466 Jul 27 | -448 Aug 6 | -430 Aug 17 |
| 23 | -520 Dec 19 | -502 Dec 30 | -483 Jan 10 | -465 Jan 21 | -447 Jan 31 | -429 Feb 12 |
| 24 | -519 May 15 | -501 May 26 | -483 Jun 5 | -465 Jun 17 | -447 Jun 27 | -429 Jul 8 |
| 25 | -519 Nov 8 | -501 Nov 19 | -483 Nov 30 | -465 Dec 11 | -447 Dec 22 | -428 Jan 2 |
| 26 | -518 May 5 | -500 May 15 | -482 May 26 | -464 Jun 5 | -446 Jun 17 | -428 Jun 27 |
| 27 | <u>-518 Oct 28</u> | -500 Nov 7 | -482 Nov 19 | -464 Nov 29 | -446 Dec 11 | -428 Dec 21 |
| 28 | -517 Apr 24 | -499 May 4 | -481 May 16 | -463 May 26 | -445 Jun 6 | -427 Jun 17 |
| 29 | -517 Oct 17 | -499 Oct 28 | -481 Nov 8 | -463 Nov 18 | -445 Nov 30 | -427 Dec 10 |
| 30 | -516 Apr 13 | -498 Apr 24 | -480 May 4 | -462 May 15 | -444 May 26 | -426 Jun 6 |
| 31 | -516 Sep 7 | -498 Sep 18 | -480 Sep 28 | -462 Oct 10 | -444 Oct 20 | -426 Oct 31 |
| 32 | -515 Mar 3 | -497 Mar 14 | -479 Mar 25 | -461 Apr 5 | -443 Apr 15 | -425 Apr 26 |
| 33 | -515 Aug 27 | -497 Sep 8 | -479 Sep 18 | -461 Sep 29 | -443 Oct 10 | -425 Oct 21 |
| 34 | -514 Feb 20 | -496 Mar 2 | -478 Mar 14 | -460 Mar 24 | -442 Apr 4 | -424 Apr 15 |
| 35 | -514 Aug 17 | -496 Aug 27 | -478 Sep 7 | -460 Sep 18 | -442 Sep 29 | -424 Oct 9 |
| 36 | -513 Feb 9 | -495 Feb 20 | -477 Mar 3 | -459 Mar 13 | -441 Mar 25 | -423 Apr 4 |
| 37 | -513 Aug 8 | -495 Aug 16 | -477 Aug 28 | -459 Sep 7 | -441 Sep 18 | -423 Sep 28 |
| 38 | -512 Jan 30 | -494 Feb 9 | -476 Feb 21 | -458 Mar 3 | <u>-440 Mar 13</u> | -422 Mar 25 |

Table 2. (Cont.)

| | 19 | 20 | 21 | 22 | 23 | 24 |
|----|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 1 | <u>-422 Aug 19</u> | -404 Aug 29 | -386 Sep 9 | -368 Sep 20 | -350 Oct 1 | -332 Oct 11 |
| 2 | <u>-421 Feb 13</u> | -403 Feb 23 | -385 Mar 7 | -367 Mar 17 | -349 Mar 28 | -331 Apr 8 |
| 3 | <u>-421 Aug 8</u> | -403 Aug 18 | -385 Aug 30 | -367 Sep 9 | -349 Sep 20 | -331 Oct 1 |
| 4 | <u>-420 Feb 2</u> | -402 Feb 13 | -384 Feb 24 | <u>-366 Mar 6</u> | -348 Mar 17 | -330 Mar 28 |
| 5 | -420 Jul 28 | -402 Aug 8 | -384 Aug 18 | <u>-366 Aug 30</u> | -348 Sep 9 | -330 Sep 20 |
| 6 | -419 Jan 21 | -401 Feb 2 | -383 Feb 12 | <u>-365 Feb 23</u> | -347 Mar 6 | -329 Mar 17 |
| 7 | -419 Jul 17 | -401 Jul 29 | -383 Aug 8 | -365 Aug 19 | -347 Aug 30 | -329 Sep 10 |
| 8 | -418 Jan 10 | -400 Jan 22 | -382 Feb 1 | -364 Feb 12 | -346 Feb 23 | -328 Mar 5 |
| 9 | -418 Jun 8 | -400 Jun 18 | <u>-382 Jun 29</u> | -364 Jul 9 | -346 Jul 21 | -328 Jul 31 |
| 10 | -418 Dec 1 | -400 Dec 11 | <u>-382 Dec 23</u> | <u>-363 Jan 2</u> | <u>-345 Jan 14</u> | <u>-327 Jan 24</u> |
| 11 | -417 May 28 | -399 Jun 7 | <u>-381 Jun 18</u> | <u>-363 Jun 29</u> | -345 Jul 10 | <u>-327 Jul 20</u> |
| 12 | -417 Nov 21 | -399 Dec 1 | <u>-381 Dec 12</u> | <u>-363 Dec 23</u> | -344 Jan 3 | <u>-326 Jan 14</u> |
| 13 | -416 May 16 | -398 May 27 | <u>-380 Jun 6</u> | <u>-362 Jun 18</u> | -344 Jun 28 | <u>-326 Jul 9</u> |
| 14 | -416 Nov 9 | -398 Nov 21 | -380 Dec 1 | <u>-362 Dec 12</u> | -344 Dec 23 | <u>-325 Jan 3</u> |
| 15 | -415 May 5 | -397 May 16 | -379 May 17 | <u>-361 Jun 7</u> | -343 Jun 17 | -325 Jun 28 |
| 16 | -415 Sep 30 | <u>-397 Oct 12</u> | <u>-379 Oct 22</u> | -361 Nov 2 | -343 Nov 13 | -325 Nov 24 |
| 17 | <u>-414 Mar 26</u> | -396 Apr 5 | <u>-378 Apr 17</u> | -360 Apr 27 | -342 May 8 | <u>-324 May 19</u> |
| 18 | -414 Sep 19 | -396 Sep 30 | <u>-378 Oct 11</u> | -360 Oct 21 | -342 Nov 2 | -324 Nov 12 |
| 19 | <u>-413 Mar 16</u> | <u>-395 Mar 26</u> | <u>-377 Apr 6</u> | <u>-359 Apr 17</u> | -341 Apr 28 | -323 May 8 |
| 20 | -413 Sep 8 | -395 Sep 19 | -377 Sep 30 | <u>-359 Oct 10</u> | -341 Oct 22 | -323 Nov 1 |
| 21 | -412 Mar 4 | <u>-394 Mar 16</u> | -376 Mar 26 | -358 Apr 6 | -340 Apr 17 | -322 Apr 28 |
| 22 | -412 Aug 28 | -394 Sep 8 | -376 Sep 18 | -358 Sep 30 | -340 Oct 10 | -322 Oct 21 |
| 23 | -411 Feb 22 | -393 Mar 5 | -375 Mar 15 | -357 Mar 27 | -339 Apr 6 | <u>-321 Apr 17</u> |
| 24 | -411 Jul 19 | -393 Jul 30 | -375 Aug 9 | -357 Aug 21 | -339 Aug 31* | -321 Sep 11* |
| 25 | -410 Jan 12 | -392 Jan 23 | -374 Feb 3 | <u>-356 Feb 14</u> | -338 Feb 24 | -320 Mar 7 |
| 26 | -410 Jul 8 | -392 Jul 19 | -374 Jul 30 | -356 Aug 9 | -338 Aug 21 | -320 Aug 31 |
| 27 | -409 Jan 1 | -391 Jan 12 | -373 Jan 23 | -355 Feb 2 | -337 Feb 14 | -319 Feb 24 |
| 28 | <u>-409 Jun 28</u> | -391 Jul 8 | -373 Jul 20 | -355 Jul 30 | -337 Aug 10 | -319 Aug 20 |
| 29 | <u>-409 Dec 22</u> | -390 Jan 1 | -372 Jan 12 | -354 Jan 23 | -336 Feb 3 | -318 Feb 13 |
| 30 | <u>-408 Jun 16</u> | -390 Jun 28 | -372 Jul 8 | -354 Jul 19 | -336 Jul 29 | -318 Aug 10 |
| 31 | <u>-408 Nov 11</u> | -390 Nov 22 | -372 Dec 2 | -354 Dec 14 | -336 Dec 24 | -317 Jan 5 |
| 32 | <u>-407 May 7</u> | -389 May 18 | -371 May 28 | -353 Jun 9 | -335 Jun 19 | -317 Jun 30 |
| 33 | <u>-407 Oct 31</u> | -389 Nov 12 | -371 Nov 22 | -353 Dec 3 | -335 Dec 14 | -317 Dec 25 |
| 34 | -406 Apr 26 | -388 May 6 | -370 May 17 | -352 May 28 | -334 Jun 8 | -316 Jun 18 |
| 35 | <u>-406 Oct 21</u> | <u>-388 Oct 31</u> | <u>-370 Nov 11</u> | <u>-352 Nov 22</u> | <u>-334 Dec 3</u> | <u>-316 Dec 13</u> |
| 36 | <u>-405 Apr 15</u> | <u>-387 Apr 26</u> | -369 May 7 | -351 May 17 | <u>-333 May 29</u> | -315 Jun 8 |
| 37 | <u>-405 Oct 10</u> | -387 Oct 20 | -369 Oct 31 | -351 Nov 11 | -333 Nov 22 | -315 Dec 2 |
| 38 | -404 Apr 4 | -386 Apr 15 | -368 Apr 26 | -350 May 7 | -332 May 17 | -314 May 29 |