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# PHILIPPE DE LA HIRE'S EIGHTEENTH CENTURY ECLIPSE PREDICTOR

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**Abstract:** We investigate the workings of an early eighteenth century instrument for predicting eclipses described by the French astronomer de la Hire in his book *Tabulae Astronomicae*.

**Keywords:** history of astronomy, astronomical instruments, eclipses, volvelles

## 1 INTRODUCTION

In the beginning of the eighteenth century there was a great interest in trying to find methods to determine the geographical longitude. One of the then current methods was to use timings of the immersions and emersions of the satellites of Jupiter; another one was to use timings of lunar eclipses. These longitude methods became obsolete with the invention and construction of precise mechanical chronometers, notably by John Harrison in the middle of the eighteenth century (see Sobel, 1995).

Figure 1 shows a picture of an instrument for predicting eclipses that can be found at the last pages of *Tabulæ Astronomicæ*, by Philippe de La Hire (1702). De la Hire (Figure 2; 1640–1718) was a French mathematician and astronomer (see Sturdy, 2014). On pages 89–94 in his 1702 book there is also a description of the instrument and an explanation of its use (written in Latin). De la Hire's instrument was intended as a tool for finding dates of lunar eclipses that could be used to determine longitude. It also predicted solar eclipses.

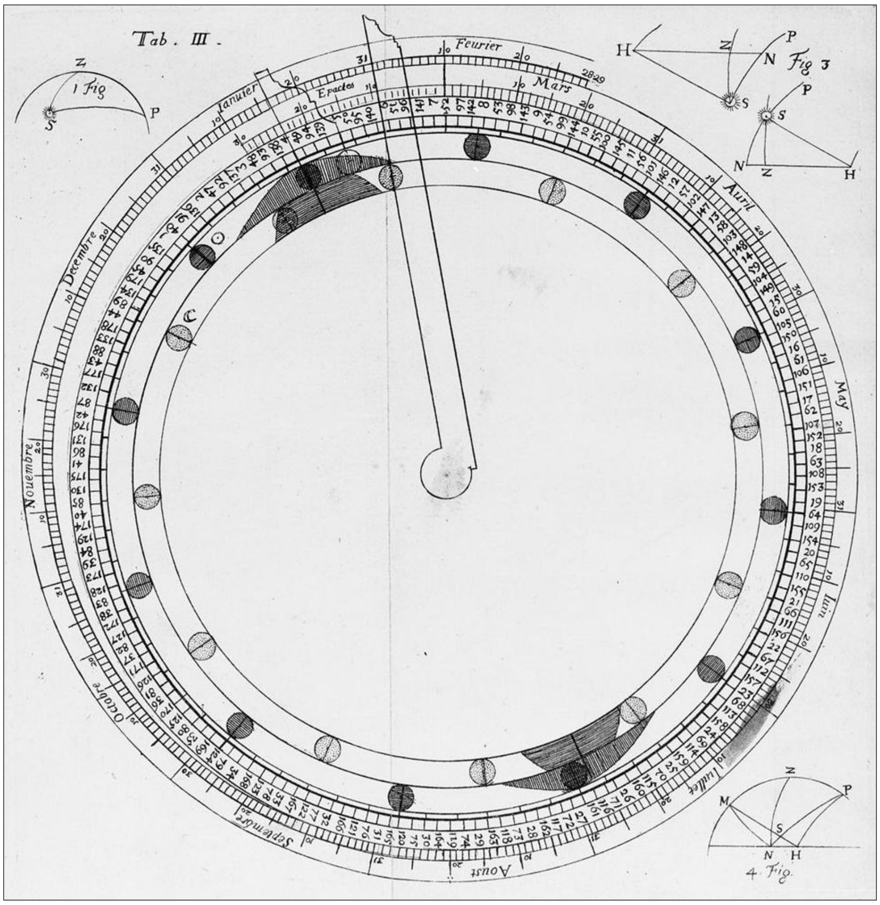


Figure 1: de la Hire's eclipse predictor (source: gallica.bnf.fr).

The use of volvelles as computing devices had a long tradition before de la Hire. A well-known and magnificent example is in *Astronomicum Caesareum* by Petrus Apianus (Apianus; 1495–1552). Based on the Ptolemaic system, it contains more than thirty ingenious and intricate volvelles for computing astronomical events, among them several for predicting eclipses in great detail. In comparison, de la Hire's instrument is less precise, but it had the advantage that it could very easily and quickly be set up.

## 2 THE INSTRUMENT

The instrument, or volvelle, consists of three disks on top of one another, with the two top disks being able to rotate around a common centre. There is also a ruler that can be used to transfer data between the disks.

The bottom disk has one turn of 346 days starting with 1 March and ending with 10 February. The extra 18/19 days in February ends the outer spiral. The reason for this is twofold: the leap day of the year will come at the end of the period and, secondly, the remaining 18/19 days at the end of February give a handy way of accounting for the difference between the Gregorian and the eclipse years (see below). There is a scale of 30 days before 1 March that can be used for finding the epacts.

The middle disk has a pair of diametrically-located shadowed regions that are centred on the lunar nodes. The shadows mark the regions in which there can be a solar or lunar eclipse. The text in de la Hire's book states that the outer shadowed region, to be used for solar eclipses, is black and the inner one, for lunar eclipses, is red. For solar eclipses the limit for an eclipse is ±16° around the nodes, and for a lunar eclipse it is ±11°; these limits correspond well with modern accepted ones. Around the edge of this disk are 179 numbered slots.

The top disk has two sets of circular holes, the outer one with thirteen consecutive new moons for solar eclipses, and the inner one with twelve full moons for lunar eclipses. The distance between the holes is a lunation or 29.53 days. The sets are marked by Sun and Moon symbols respectively. When any of these holes is above the shadowed regions, the amount of shadow shown through the hole is an indicator of the size and kind of the eclipse. The top disk also has a tab for setting the lunar year on the middle disk and the date on the bottom disk.

## 3 THEORY

The instrument uses mean quantities of the Sun and the Moon, thus the indicated eclipse dates may deviate by a day from the true ones. Times are civil, i.e. reckoned from midnight to midnight, and refer to the meridian of Paris.

Fundamental parameters:

The Gregorian year: $GY$ = 365.2425 days
The synodic month $SM$ = 29.53059 days
The draconic month $DM$ = 27.21222 days, lunar period from ascending node to ascending node.
The lunar year $LY$ = 12 · SM = 354.36700 days
The eclipse year $EY = (SM \cdot DM)/(SM - DM)$ = 346.61979 days, the period of return of the Sun to the lunar node.

De la Hire uses values for some of these parameters that are slightly different from modern values, something that will not seriously affect the arguments presented below.

The difference between the lunar year and the eclipse year:

$LY–EY$ = 354.36700 – 346.61979 = 7.74721 days

Figure 2: An engraving of de la Hire made during his lifetime (en.wikipedia.org).

The circle with 179 numbered slots on the middle disk is arranged as follows:

1 46 91 136, 2 47 92 137, … , $n$ $n$+45 $n$+90 $n$+135, … , 45 90 135 1, i.e. with every fourth slot the number increases by 1 and after four rounds we are back at the origin.

The 179 slots on the middle disk correspond to one eclipse year on the bottom disk. Thus we have that 7.7472 days correspond to

(7.7472/346.61979) ·179 = 4.0008 ≈ 4 slots very nearly.

Thus, these slots can be used to correct for the yearly movement of the lunar nodes relative to the Moon. Another way of expressing the relation above is to say that 179 lunar years are almost exactly equal to 183 eclipse years:

179 $LY$ = 63431.69 days, and
183 $EY$ = 63431.42 days

The difference between the Gregorian year and the eclipse year is 18.6227 days ($GY - EY = 365.2425 - 346.61979 = 18.6227$). This number allows us to move from one eclipse year to another.

De la Hire has placed the descending node of the Moon at the lunar year 4 that started on 17 January 1684 at 1:38 hours. A modern calclation shows that indeed the mean new moon at that time actually was very close to the descending node and that there consequently was a solar (annular) eclipse. It was not visible in France; the Sun being below the horizon at the time.

## 4 MANIPULATION OF THE DISKS

1) Set the tab of the top disk to the lunar year number of the middle disk.
2) Move the two top disks *together* until the top disk tab points to the start date of the lunar year taken from de la Hire´s table below.
3) If the date of the lunar year falls in November, December, January, or February, it may be necessary to move the two top disks together *back* (anti-clockwise) by 18 or 19 days in order to see the eclipses from 1 March and on. This will move the settings to the next eclipse year.
4) In order to see eclipses *before* the start date of a given lunar year, set up the disks for the *previous* lunar year.

Here are four examples.

1) AD 1703. The lunar year is 24 in the sequence with start of the lunar year on 14 June. Setting up the disks according to 1) and 2) above results in a partial solar eclipse on 14 July, a partial solar eclipse on 8 December, a total lunar eclipse on 29 June and another one on 23 December. Note that there seems to be a partial solar eclipse on 22 June but this Moon belongs to the end of the current lunar year and is false. In order to examine the part of the solar year that comes before the start of lunar year 24, we use rule 4) above. Set up the disks for lunar year 23, start of the lunar year 25 June. There will now be a partial solar eclipse on 17 January 1703 and a partial lunar eclipse on 3 January 1703.
2) AD 1680. This is lunar year 179 with start 29 February. We set up the disks accordingly and to see possible eclipses after 29 February we move to the next eclipse year by moving the two top disks together back 19 days (1680 is a leap year) until the tab points to 1 March /10 February. There will be a total solar eclipse on 30 March and another one on 22 September.
3) AD 1681. This is lunar year 1 with start 18 February. We set up the disks and move them together back 18 days. The tab will point to 30 January. There is now a partial solar eclipse on 20 March and another one on 12 September and a partial lunar eclipse on 4 March and one on 29 August.
4) AD 1748. This is eclipse year 70 with start 30 January. We set up the disks. Before we move them we note that there is a partial solar eclipse on 30 January and a partial/ total lunar eclipse on 14 February. We then move the disks back 19 days (1748 is a leap year). The tab now points to 11 January and we then see a total solar eclipse on 25 July and a partial lunar eclipse on 9 August.

## 5 LUNAR YEAR TABLE

The table that de la Hire gives for the lunar years and their starting dates and times is shown below in Table 1.

Table 1: De la Hire's lunar year table.

| Anni Lunar. | Usuales. | | | Dies. | H. | M. | Anni Lunar. | Usuales. | | | Dies | H. | M. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 179. | 1680. | B. | Febr. | 29 | 14 | 24 | 51. | 1729. | | August. | 24 | 7 | 44 |
| 1. | 1681. | | Febr. | 17 | 23 | 13 | 52. | 1730. | | August. | 13 | 16 | 32 |
| 2. | 1682. | | Febr. | 7 | 8 | 1 | 53. | 1731. | | August. | 3 | 1 | 21 |
| 10. | 1689. | | Novem. | 12 | 6 | 30 | 54. | 1732. | B | Jul. | 22 | 10 | 9 |
| 20. | 1699. | | Julij, | 26 | 22 | 37 | 55. | 1733. | | Jul. | 11 | 18 | 58 |
| 21. | 1700. | | Julij, | 16 | 7 | 26 | 56. | 1734. | | Jul. | 1 | 3 | 46 |
| 22. | 1701. | | Julij , | 5 | 16 | 14 | 57. | 1735. | | Jun. | 20 | 12 | 35 |
| 23. | 1702. | | Junij, | 25 | 1 | 3 | 58. | 1736. | B. | Jun. | 8 | 21 | 23 |
| 24. | 1703. | | Junij, | 14 | 9 | 52 | 59. | 1737. | | Maij, | 29 | 6 | 12 |
| 25. | 1704. | B. | Junij, | 2 | 18 | 40 | 60. | 1738. | | Maij , | 18 | 15 | 1 |
| 26. | 1705. | | Maij, | 23 | 3 | 29 | 61. | 1739. | | Maij , | 7 | 23 | 49 |
| 27. | 1706. | | Maij, | 12 | 12 | 17 | 62. | 1740. | B. | April. | 26 | 8 | 38 |
| 28. | 1707. | | Maij , | 1 | 21 | 6 | 63. | 1741. | | April. | 15 | 17 | 27 |
| 29. | 1708. | B. | Aprilis, | 20 | 5 | 55 | 64. | 1742. | | April. | 5 | 2 | 15 |
| 30. | 1709. | | Aprilis, | 9 | 14 | 43 | 65. | 1743. | | Mart. | 25 | 11 | 4 |
| 31. | 1710. | | Mart. | 20 | 23 | 32 | 66. | 1744. | B. | Mart. | 13 | 19 | 53 |
| 32. | 1711. | | Mart. | 19 | 8 | 21 | 67. | 1745. | | Mart. | 3 | 4 | 41 |
| 33. | 1712. | B. | Mart. | 7 | 17 | 9 | 68. | 1746. | | Febr. | 20 | 13 | 30 |
| 34. | 1713. | | Febr. | 25 | 1 | 58 | 69. | 1747. | | Febr. | 9 | 22 | 18 |
| 35. | 1714. | | Febr. | 14 | 10 | 47 | 70. | 1748. | B. | Januar. | 30 | 7 | 7 |
| 36. | 1715. | | Febr. | 3 | 19 | 35 | 71. | 1749. | | Januar. | 18 | 15 | 56 |
| 37. | 1716. | B. | Januar. | 24 | 4 | 24 | 72. | 1750. | | Januar. | 8 | 0 | 44 |
| 38. | 1717. | | Januar. | 12 | 13 | 12 | 80. | 1757. | | Octob. | 12 | 23 | 15 |
| 39. | 1718. | | Januar. | 1 | 22 | 1 | 90. | 1767. | | Jun. | 26 | 15 | 20 |
| 40. | 1718. | | Decem. | 22 | 6 | 50 | 100. | 1777. | | Mart. | 9 | 7 | 26 |
| 41. | 1719. | | Decem. | 11 | 15 | 38 | 110. | 1786. | | Novem. | 20 | 23 | 33 |
| 42. | 1720. | B. | Novem. | 30 | 0 | 27 | 120. | 1796. | B. | August. | 3 | 15 | 39 |
| 43. | 1721. | | Nov. | 19 | 9 | 16 | 130 | 1806. | | April. | 17 | 7 | 45 |
| 44. | 1722. | | Nov. | 8 | 18 | 4 | 140. | 1815. | | Decem. | 29 | 23 | 52 |
| 45. | 1723. | | Octob. | 29 | 2 | 53 | 150. | 1825. | | Septem. | 11 | 15 | 58 |
| 46. | 1724. | B. | Octob. | 17 | 11 | 41 | 160 | 1835. | | Maij, | 26 | 8 | 4 |
| 47. | 1725. | | Octob. | 6 | 20 | 30 | 170 | 1845. | | Febr. | 6 | 0 | 11 |
| 48. | 1726. | | Septem. | 26 | 5 | 19 | 1. | 1854. | | Octob. | 20 | 16 | 17 |
| 49. | 1727. | | Septem. | 15 | 14 | 7 | | | | | | | |
| 50 | 1728. | B. | Septem. | 3 | 22 | 55 | | | | | | | |

The letter 'B.' stands for bissextile (leap year). Note that the dates from years 1806 and later should be one day later as de la Hire has neglected that 1800 was not a leap year.

## 6 A NOTE ON EPACTS

In the ecclesiastical calendar, the epact is the age of the Moon on a specific date, calculated by cyclical reckoning. In the Julian calendar, this date is 22 March and in the Gregorian calendar it is the start of the year. De la Hire uses mean astronomical reckoning and, for the instrument, the Moon's age on 1 March. The distance between 1 January and 1 March is 59 or 60 days, very close to two lunar months of 29.5 days. Thus de la Hire's epact on 1 March is very nearly the epact in 1 January and also nearly the same as the Gregorian epact.

De la Hire has tables (de la Hire: Tabulae, 38) for calculating his epact for any date but they are quite difficult to work with as he uses expired years, expired days and astronomical time, from noon to noon and leap years have to be treated specially.

In order to find the epact on 1 March using the instrument, you set it up for the *previous* year, move to the next eclipse year, and then read off the epact for the new moon that falls within the range of the epact scale on the bottom disk.

Here is an example.

What is the epact on 1 March 1703? Set up the instrument for 1702, lunar year 23, with start date 25 June. Then move the middle and top disks together back 18 days (1703 is not a leap year) and finally read off the epact as 11. The Gregorian epact is 12 (Catholic Encyclopedia).

## 8 REPLICA

Those who would like to build and use a replica of the eclipse predictor can download a PDF document with complete printable drawings of the instrument and an assembly instruction. It also includes de la Hire's table above (corrected) and a continuation of that table for the years 1800–2067. The volvelle works quite well also for these more modern years. You will find the material on the link http://www.thep.lu.se/~larsg/EclipsePredictor.pdf

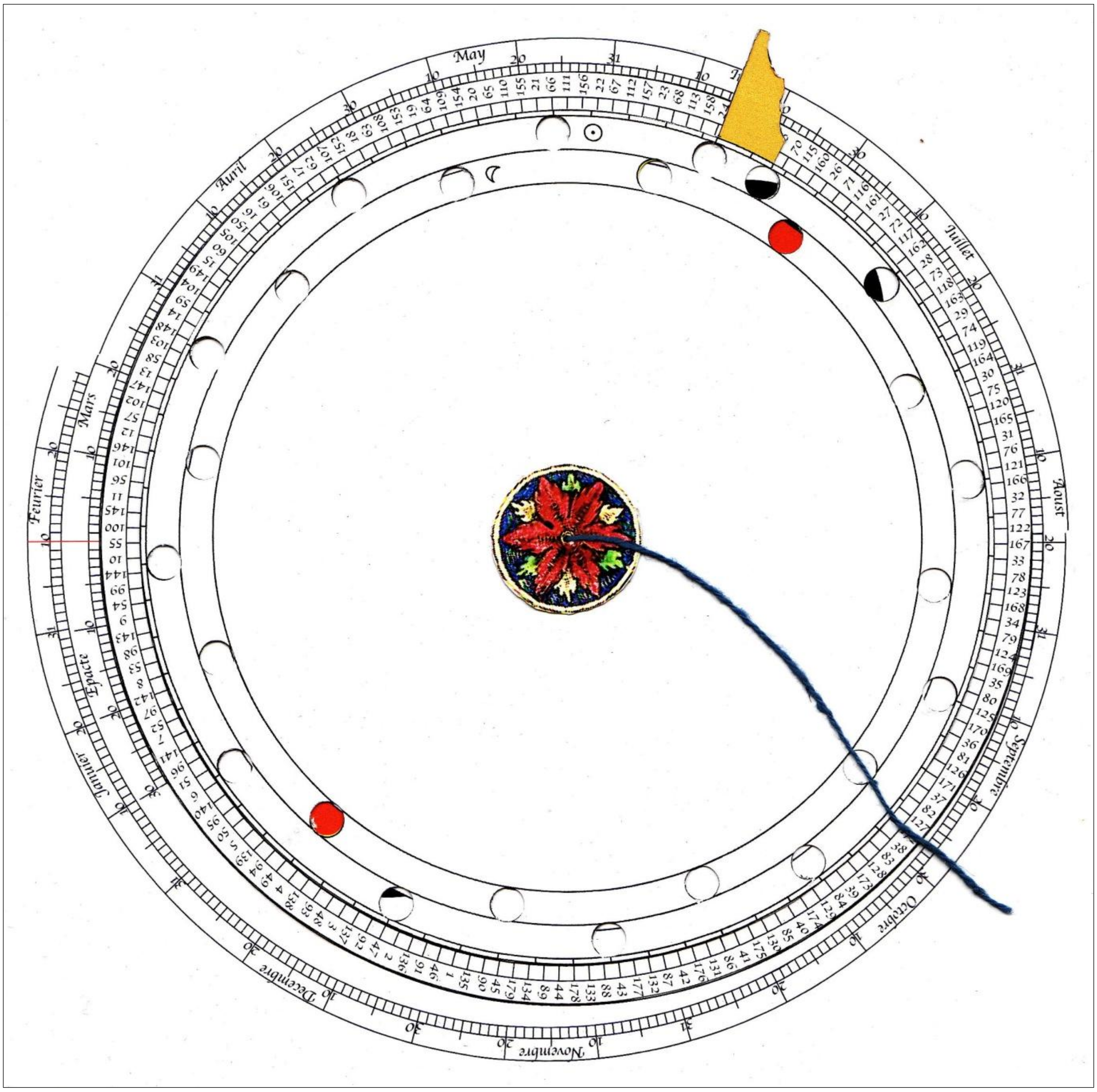


Figure 3: The replica of the de la Hire eclipse predictor set up for the year AD 1703 (photograph: Lars Gislén).

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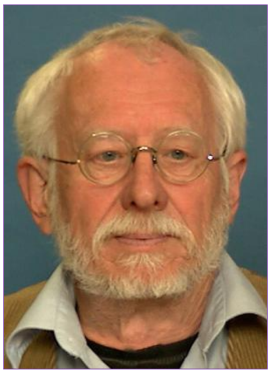
Dr Lars Gislén is a former lector in the Department of Theoretical Physics at the University of Lund, Sweden, and retired in 2003. In 1970 and 1971 he studied for a Ph.D. in the Faculté des Sciences, at Orsay, France. He has been doing research in elementary particle physics, complex system with applications of physics in biology and with atmospheric optics. During the last fifteen years he has developed several computer programs and Excel sheets implementing calendars and medieval astronomical models from Europe, India and South-East Asia (see http://home.thep.lu.se/~larsg/).


Dr Chris Eade has an M.A. from St Andrews and a Ph.D. from the Australian National University. In 1968 he retired from the Australian National University, where he had been a Research Officer in the Humanities Research Centre before moving to an affiliation with the Asian Studies Faculty, in order to pursue his interest in South-East Asian calendrical systems. In particular, research that he continued after retirement concerned dating in the Thai inscriptional record, in the horoscope record of the temples of Pagan and in the published record of Cambodia and Campa.