How Newton inspired China's calendar

In 1702, Newton's lunar theory was received enthusiastically as a means to determine longitude, but it has long been neglected – except in China, as **N Kollerstrom** explains.

Isaac Newton composed a nowadays little-appreciated *Theory of the Moon's motion* in 1702, in between the first and second editions of his *Principia*. It was a recipe for finding the Moon's longitude, as was then a thing greatly longed-for as a means for finding Universal Time and thereby ascertaining longitude at sea. It was much reprinted in the early decades of the 18th century, more than his other publications, but then fell into neglect among historians in the 19th and 20th centuries (Kollerstrom 2000). It did so because it lacked anything that might be called Newtonian theory, making no mention of gravity, and instead had several epicycles, wheels within wheels, not quite the picture people had of Newton's work. There has been debate ever since over whether gravitational theory guided him in its formulation. This lunar recipe started off with mean motions, then reached its goal in seven steps.

Britain's first astronomical theory

In Europe in the first half of the 18th century, eight different sets of tables were published by astronomers using the Newtonian "theory", of which the best-known were those by Edmond Halley at Greenwich and Pierre Lemonnier in Paris. These tables shared the characteristic Newtonian "seven-step" procedure. Starting from a uniform "mean Moon", equations were added successively, where an "equation" signified an adjustment or correction to improve the value. The fourth of these equations was the major Equation of Centre, giving a correction up to 6° with the "Variation" as the fifth equation giving a correction up to 1° The smallest of these equations went up to 1′ or 2′. Out of the seven steps, four were invented by Newton (probably in the 1690s). Alan Cook is presently investigating the linkage of these equations to gravity theory.

At the core of this lunar theory was the mechanism devised by Jeremiah Horrocks in the 1630s (Chapman 1990), in which the Earth was at one focus of the Keplerian lunar ellipse while its centre moved around an epicycle with respect to its centre on the apse line (joining the mean apogee–perigee positions). It revolved once per Sun-apse conjunction, as the apse line oscillated by some 12° and the eccentricity by about 20%. It was Britain's first astronomical theory.

Isaac Newton, as shown in the frontispiece of the third edition of his *Principia,* 1726 (RAS).

The motion of the Moon was a challenge to early astronomical theorists, Newton included. Newton's theory of lunar motion does not refer explicitly to his theory of gravitation, and it fell into disuse. Computer calculations based on his theory show its accuracy for the period in which it was formulated. Elements of the theory were used to establish the eclipse calendar in China in the 18th century, a calendar that continued to be used into this century. Curiously, it was the lack of any reference to the theory of gravitation that made it possible for this theory to be brought to China by Jesuit missionaries.

Kepler had been hesitant about applying ellipses to the lunar orbit, but the Horroxian model did so, in relation to the apogee–perigee cycle, whereby the apse line formed its long axis, making it revolve once per nine years. This created a conceptual nightmare, in that the Horroxian model used two incompatible ellipses. Newton explained the Variation by making the lunar orbit an ellipse with Earth at its centre (not at a focus), with syzygy (joining Full and New Moon positions) as its short axis and the lunar quarters on its long axis. This ellipse revolved yearly, and had a much larger eccentricity than the apogee–perigee ellipse. How could these two be reconciled? This may have been why Newton remarked to Halley that the Moon was the one thing that ever made his head ache.

I constructed the "error envelope" of this Newtonian procedure by modelling it with a spreadsheet and then comparing its output with modern longitude positions for the historical period. This showed that its maximal error was 5 or 6 arcminutes, to which another 2 need to be added because, over its main period of use, three or four decades after its construction, errors had accumulated by its mean motion. Gregory and Halley were to claim something like 2 arcminutes of accuracy for it and debates over this matter still continue (Cook 1998). In practice there would have been errors from interpolating tables, not shown in such a computer reconstruction.

The journey east

What Newton published in 1702 lacked any trace of gravity theory – which was why it could be admitted into China. When Western ideas were greatly frowned upon, and the theory of universal gravitation was ideologically unsound, this set of rules for finding the Moon's position was readily assimilated. The Chinese during the 18th century adhered to a geocentric world-view, believing that the Earth did not move, and wished to absorb no Western astronomical theory more recent than that of Tycho Brahe. Isaac Newton's *Theory of the Moon's motion* of 1702 came to be used in China for the purpose of eclipse prediction, and not, as was the case in Europe, for the finding of longitude. In 1726 a version of this Newtonian theory was published (anonymously) by Nicasius Grammatici in Germany at Ingolstadt, and it was this version that was imported into China by Jesuit missionaries.

In 17th-century China, failures to predict solar eclipses were still happening, and had grave implications for the state religion. The Empire Astronomy Bureau failed to predict the solar eclipse of 21 June 1692 and this caused distress at the Emperor's palace. Prayers had to be said and the astronomers responsible were driven into exile. In the next century, the prediction of the solar eclipse on 15 July 1730 was successful. This used old tables of 1723 based on circular motion with epicycle and deferent. The Tychonic scheme was being used in China in the early decades of the 18th century.

The German Jesuit missionary Ignatius Koegler was director of Peking's Empire Astronomy Bureau from 1722 to 1737. The first indication of more modern Western astronomy appears as the publication of tables bearing the names of Cassini and Flamsteed in 1738, added as part of a 10-volume appendix by Koegler to what was then the standard treatise on astronomy *Leih Seang K'aou Ching* (Wylie 1902). In 1736, the administrator of the Qing dynasty organized a group to revise and enlarge the tables. The Jesuit missionaries Koegler and Andrt Pereira from Portugal drew up an improved astronomical system in 10 volumes called *LiXiang KaoCheng HouBian* (*LKH*) in collaboration with 40 Chinese astronomers, at the order of the Emperor, from 1736 to 1742, published in 1742. The Chinese name for Newton, *Nei Duan,* first appears in this document.

It was only quite recently, in the 1990s, that Dr Lu Dalong of the Chinese Academy of Sciences realized that the lunar theory contained within *LKH* was based on Newton's lunar "theory" of 1702 (private communication). One or two of its constants had been adjusted to accord with the *Principia* of 1713. Its volume II is the mathematical–geometrical theory of lunar equations, composed in 11 sections, and it has many "Newtonian" constants, but no theory of universal gravitation, as was in contradiction to missionary doctrine. The Jesuits themselves believed in the heliocentric system, and may have had private conversations about the Earth moving, but could not state this matter in public in China (Needham 1959).

From this body of theory, a calendar was derived, lasting from 1742 to 1924. This calendar is based on the 33-year pattern of leap years (there is a rather exact accord between days and years over this interval, with eight days being intercalated per 33 years) and is a uniquely Chinese creation. Each year it was published as a book and included material of agricultural significance, plus the correct days to marry, to bury the dead, and when ventures would be lucky. The problem of predicting solar and lunar eclipses had been solved.


A view of the Peking Observatory in the 1880s (from RAS MS Dreyer 7).

Eclipses and Keplarian ellipses

Competition existed between the Western Jesuits and the Chinese astronomers, as regards the propagation of Jesuit doctrine, and one who was capable of making a clear eclipse prediction could thereby gain an audience to see the Emperor. To quote Dalong: "Koegler and Pereira did not explain the theory on which the calendar table was based, and did not reveal the method of using the table, which was directly arranged as an appendix to *LKH*. In the Bureau, it was only Ming Antu, Director of the Empire Astronomical Bureau, i.e. the national observatory in Peking, who had access to this table, and it is certain that the Administration of the Empire was not satisfied with the result," (Dalong 1992).

Thus the Empire Astronomy Bureau did over this period accept Keplarian ellipses for the motion of the luminaries, around a stationary Earth (Hashmoto 1997).

By comparing the constant terms of the Chinese lunar theory, Dr Dalong and I discerned that some values had been taken from Grammatici's opus, some from the 1713 *Principia* and some from the 1702 *Theory of the Moon's motion*. These differences are relatively small and would have little effect upon the final outcome, but show that those compiling the calendar evidently felt they had a choice.

The Chinese text *LKH* had a worked example for finding the lunar longitude (plus nodes, apse line, perihelion and solar longitude positions, as the theory also generated) for a date given as 45 days after the winter solstice of 1742; it also gave solar and lunar mean-motion positions for several other solstice dates. These revealed the startling fact that the Chinese longitudes given all had 90° subtracted from their European equivalents, i.e. were measured not from zero Aries but from zero Cancer, the summer solstice rather than the vernal equinox position. Only after that 90° adjustment would my computer reconstruction of Newton's lunar theory accord with the Chinese results. After transforming the Chinese time-values to GMT, the agreement was then within arcseconds.

The Grammatici text as used in China had a key role in enabling the accurate prediction of eclipses. This was required for the proper functioning of state affairs, and was kept well into the 20th century. In Britain and Europe, Newton's 1702 epicycle-laden lunar theory was swiftly forgotten around the mid-18th century, as an effective lunar theory derived from gravity theory arrived from the Continent. In China this 1702 "theory" lived on, ironically because of its absence of allusion to gravity. It required a modern computer reconstruction to show this presence in the Chinese texts. ●

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