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SEARCHING FOR NEW GEOPHYSICAL KNOWLEDGE AS REVEALED BY ANCIENT OBSERVATIONS

THE MOON'S ACCELERATION AND ITS PHYSICAL ORIGINS: Vol. 1—As Deduced from Solar Eclipses and Vol. 2—As Deduced from General Lunar Observations
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Published by The Johns Hopkins University Press, Baltimore and London, 1979 (Vol. 1), 596 pp., and 1984 (Vol.2), 320 pp.

Robert Newton uses his extensive skill in practical astronomy to study the literature of astronomy, starting with Tycho Brahe and stretching backward to the ancient Babylonians and Chinese. His goal is to find observations to improve our knowledge of the decelerations of the earth's rotation and of the moon's orbital motion. These decelerations may lead in turn to a better theoretical understanding of the tides, to knowledge of the changes with time of the earth's moment of inertia, or even to tests of the constancy of the gravitational constant. Analysis of ancient observations also gives us historical insights into the methods of ancient astronomy. This work is unusually wide-ranging and interesting; it is also controversial.

It is characteristic of Newton's work that he corrects his own errors and those of other scholars as he goes; thus the last volume is most important. But this review must also discuss Newton's 1977 book, *The Crime of Claudius Ptolemy,*[1] because Ptolemy's *Almagest*[2] seems to be a necessary part of any discussion of ancient astronomy and because Ptolemy is a focus for the controversy in Newton's writings.

In Volume 2, Newton lists the observations in inverse chronological order. He describes a method for correcting Tycho Brahe's sixteenth century observations of the moon for temperature-dependent refraction. We have modern records for the monthly mean temperatures at more than a thousand stations around the world, and one station is only about 25 kilometers from Tycho's island observatory. Tycho's refraction correction must be removed and the modern one added.

Because Tycho's time is relatively close to our time, much better accuracy is required for his observations than for earlier ones where the time shift (which increases with time squared) becomes large. Newton concludes that Tycho's observations are not accurate enough for his needs. Tycho did not describe his clock in sufficient detail to allow Newton's skill at corrections to operate. There are also inconsistencies between observations made with Tycho's different instruments.

The latest observations that pass Newton's tests for consistency and accuracy are those of solar and lunar eclipses and of solar transits made by Regiomontanus and Walther in Nuremberg and other central European locations in the fifteenth century. Walther was both patron and assistant to Regiomontanus and kept making observations of the sun for a quarter of a century after the death of Regiomontanus.

Ancient tables of the sun and moon serve to calculate the decelerations too. A set of ancient observations is better because the consistency of the observations gives an evaluation of the errors. Newton considers the Alfonsine tables from the thirteenth century at Toledo, Spain, and those of Levi ben Gerson a half century later at Orange, France. The position of the moon relative to the sun (elongation) is the most favorable quantity for estimating the deceleration of the earth, but for neither set of tables does he find an accurate result.

The method is to compare the elongation from the table at a time close to the original observations from which the table is made, to that calculated from the modern integration for solar, lunar, and planetary positions, the DE102 ephemeris from the Jet Propulsion Laboratory. (A value for the tidal deceleration of the moon, 28 arc seconds per century per century, is derived in Volume 1 and adopted in Volume 2.) Newton treats each table or observation individually and forms rough estimates of its accuracy and of the deceleration. The accepted observations are then analyzed together. Volume 1 contains extensive notes on individual solar eclipses from 720 BC to 1567 AD; included are documents from many parts of Asia and Europe. The earliest of these eclipses comes from the *Annals of Lu,* a work compiled by Confucius (551–479 BC). The *Annals of Lu* contain political, meteorological, and astronomical data over about two and a half centuries. There are 37 solar eclipses but no lunar eclipses.

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Newton found 34 solar eclipses useful for the determination of the earth's deceleration.

Volume 1 also contains a long appendix on Roman calendars, one of which is the Julian calendar, basic to historical studies and to our own civil calendar. The Julian calendar was not properly followed in the first years of its use, 45 to about 8 BC, because during these years a leap year day was added every three years instead of every four. Augustus Caesar then omitted three leap years until the calendar was back in synchronization with its original form. In 8 AD, the regular leap year schedule was resumed.

Although we consider the year to begin on January 1, different conventions were in use during the Middle Ages. What al-Battani called the Roman Calendar in 900 AD began each year on March 1, for example.

Muller and Stephenson,[3] Stephenson,[4] and Lambeck[5] have argued for the existence of "population bias" in Newton's least squares solutions, caused by the irregular distribution of the observing sites for the ancient solar eclipses. Least square fits, say Muller and Stephenson, force the eclipse paths to go through or nearly through the observing sites. They show, for the eclipse of August 22, 1039, two paths across Europe, one implied by Newton's least square analysis and the other calculated from their set of eclipses with J.K. Fotheringham's[6] method of "linear inequalities." They label the longitude shift between the two paths (12.5 degrees) "population bias." This does not make statistical sense because it has not been established that their path is free of error. Newton defends his position in Chapter X of Volume 2 by pointing out that, even if there were only a single observing site, there is no bias in the least square estimator if the true paths are equally likely to pass on either side of the single site.

I have examined Oppolzer's[7] book on ancient eclipses to form an opinion on the uniformity of the distribution of eclipse paths. Insofar as "eyeball" estimates of Oppolzer's numerous maps can be made, they seem uniform. Speaking statistically, least square estimators are not biased, but if the parent population is sampled in a selective way, the analysis of the sample will show the selection effects. One could pursue further the search for the existence of "population bias" by dividing Newton's set of eclipse observations into two subsets, one where the moon was near the ascending mode and one where the moon was near the descending mode, and finding the accelerations separately for the two subsets. In the meantime, I doubt the existence of any bias in Newton's analysis.

Newton has based his analysis in the final chapter on an assumed deceleration for the moon (28 arc seconds per century and can thus determine a deceleration of the earth from each observation. (He gives coefficients for converting the results for other values of the moon's deceleration, but the two decelerations are strongly correlated and thus not accurately obtainable, separately.)

Many scholars, including Newcomb, Cowell, Fotheringham, Dicke, and Curott, as well as Muller and Stephenson (op. cit.), have investigated the ancient eclipses, and there are also early investigations of the equinox observations. Newton's analyses are more extensive, critical, and thorough. Newton was the first scientist in our century to realize that Ptolemy's observations must not be used for scientific purposes; the reasons are reviewed below.

A principal result of the study is a small time dependence in the earth's deceleration. Newton represents the fractional deceleration as a quadratic function of time. The expression derived in Volume 1 from solar eclipses gives a very similar expression to that derived in Volume 2 from lunar eclipses and other lunar observations. He concludes that the deceleration of the earth is variable over many centuries and gives formulas for predicting it.

I consider this result plausible and likely, but not yet beyond question. It lacks a theoretical interpretation, but the very well established decade fluctuations in the earth's rotation also do not yet have a convincing theoretical explanation.

On the historical side, Newton explains in Volume 2 why he did not use any observations from the *Almagest*, and he devotes an appendix to the library at Alexandria in Ptolemy's time. Ptolemy failed to refer to or to show that he was familiar with many relevant books that were once present in the library, books by Aristarchus, Eratosthenes, and Berossus. Newton attributes the omissions to general neglect of the library by successive Alexandrian kings. Another explanation for Ptolemy's ignorance follows.

When Julius Caesar visited Alexandria in 45 BC, he must have been attracted to the maps in the library. Then, as now, reliable maps were a vital part of military operations, and Caesar, a general foremost, could not ignore the implications of those maps. He could improve his own campaign and deny such improvements to his enemies by taking possession of all the maps in the library. I assume that Caesar assembled all the maps and books on geography for shipment to Rome and that he considered astronomy to be a part of geography. These were the books that Seneca reported destroyed by fire in the rebellion of that year.

Caesar's own account of the rebellion mentions that he burned some ships in the harbor, and E. O. Parsons' book, *The Alexandrian Library,*[8] suggests that the fire spread to warehouses near the docks. Parsons concluded that Cleopatra had given certain books to Caesar and that Seneca's account of 70,000 books burned represents an inflated figure. A military use for the books seems more likely.

Thus it seems that more than a century later, in Ptolemy's time, the library was not well supplied with books on astronomy. Ptolemy had copies of the works of Hipparchus and of some ancient tables. He also had some ancient instruments, probably in bad condition; judging from his descriptions of these instruments, I doubt that he was familiar with their use.

In the *Almagest*, Ptolemy describes about a hundred astronomical observations of the sun, moon, and planets; and he gives us a catalog of just over one thou-

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sand stars containing celestial latitude, longitude, and magnitude. In *The Crime of Claudius Ptolemy,* Newton concluded that all of Ptolemy's own observations of the sun, moon, and planets that can be tested are fabricated. Many observations that he attributed to other astronomers are also fabricated.

How can these conclusions be reached? To begin with, there is perfect agreement between the observations and the tables in the *Almagest,* or in a few cases between the observations and a simple theory given in the *Almagest* and other given observations. Thus all the observations can be readily calculated, while there are almost no practical details for the observations.

Observations of equinoxes and solstices agree exactly with Ptolemy's value for the tropical year and quoted earlier observations, and yet they have longitude errors (determined by comparison with modern theory) of more than a degree. Generations of scholars have searched, unsuccessfully, for alternate explanations for these alleged observations.

Ptolemy describes a method for finding the distance of the moon, one which depends critically on the latitude of the observer. He gets a fairly accurate distance, but his latitude for Alexandria is off by far too much. Hipparchus had determined the distance earlier, so Ptolemy knew the right answer.

Newton examined the star catalog and found from the distribution of the fractional parts of degrees of longitude that a constant whose fractional parts is 40 minutes had been added to them. The precession constant Ptolemy used, and the time span between Ptolemy and Hipparchus, give 2 degrees 40 minutes for the longitude shift that Ptolemy thought existed.

Pedersen[9] has pointed out that certain observations of inner planets seem quite impossible because they must be made in the daytime. However, they are presented by Ptolemy in exactly the same way that he describes nighttime observations.

Another examination of the star catalog has been made by Dennis Rawlins[10] who supposed that there was a fixed error in the position of the equinox on the armillary sphere that Ptolemy claimed to use for observing star positions. There should also be a substantial periodic error in the measured latitudes, but none can be detected. Rawlins concluded that the longitudes were computed, not measured. He investigated the stars near the southern limit of the star catalog and those naked-eye stars nearby but not in the catalog. He concluded from a statistical analysis that the star catalog is based on observations at a latitude of 36 degrees made near the year 135 BC. Both of these values apply to Hipparchus, and the corresponding values for Ptolemy are much less probable.

I have recently studied the tables of mean longitudes of the sun, moon, and planets from the *Almagest* to determine when they are in best agreement with modern theory. If Ptolemy were an inaccurate observer and made the tables, the dates of agreement would show a wide scatter about his lifetime. My results show the dates of agreement all fall between two and four centuries before his lifetime, hence he did not make the observations for the tables. Since the tables and the observations agree, it follows that the tables are the source of the observations.

Newton's book on Ptolemy seems to me an especially valuable contribution, both to history and to astronomy. Many earlier astronomers have doubted the validity of particular observations in the *Almagest,* including Flamsteed, Halley, Lemònnier, Lalande, Delambre, Tannery, and Peters and Knobel. But Newton has made a comprehensive and explicit analysis of all the observations in the *Almagest.*

The use of the word "crime" in the title of Newton's book has brought forth many objections from historians. Newton argues that we would be better off in our knowledge of ancient astronomy if Ptolemy had never lived, for the seeming perfection of the *Almagest* prevented the copying of earlier books on astronomy that contained genuine observations. This argument is especially unpalatable to Owen Gingerich[11] who states that Ptolemy was the greatest astronomer in antiquity. Such later scientists as Isaac Newton and Albert Einstein also put theory ahead of observations, says Gingerich, and Ptolemy may have chosen from a large number of observations those that agreed with his tables. I prefer not to use these arguments myself. Curtis Wilson has pointed out that if Ptolemy had not lived, perhaps we would have no remains to consider at all. Whether Ptolemy was a great astronomer or not, we must pay attention to his book if we are going to study the history of astronomy.

I accept Newton's view of Ptolemy and wish to search for Ptolemy's motives. What in the world could have caused him to make up all those observations? We know from comparisons with modern theory that his tables of the sun and the moon could be used to make calculations, accurate to a fraction of an hour, of the times and also of the appearances of lunar eclipses many centuries before and after his time. The tables do not give accurate positions relative to the vernal equinox, however. A lunar eclipse is so conspicuous an event that everyone can see one if the weather permits. I imagine that there were timekeepers at Alexandria who could tell him the hour of a lunar eclipse, and that he could calculate from existing tables that the observation and table agreed. Living at a time when astronomy had nearly vanished, he had no one to teach him to observe or to explain how the tables were made. He looked at the ancient instruments, so badly corroded that he could not count the divisions, and he decided to attempt to preserve the ancient knowledge of astronomy for the future. He must have considered it important not to admit his ignorance, for the work of a ignorant person might be discarded, and with it the ancient truths of astronomy. So he fabricated almost all of the observations, with the tables as his guide. But he left many intentional clues to help later generations to understand. He called his treatise on astronomical theory and observation "Mathematical Composition," and for his own name he gives us the impossible combination of the name of a Roman emperor and that of the Macedonian kings of Egypt.

Reader, if you saw a new book on the library shelf entitled *The Complete Book of Economics* by MacArthur Tojo, you ought to know it to be a spoof. Ptolemy's spoof had a serious purpose—to preserve the old astronomical tables and some related concepts—but we must avoid taking it too seriously.

In summary, Newton's books are interesting and fundamental investigations into ancient astronomy for modern use. They contain extensive and meticulous references and many examples of how to recognize real observations. The results have already completely changed our view of Ptolemy's methods of working.

Newton gives us new results on the secular deceleration of the earth's rotation that have applications to geophysics, to tidal theory, and possibly to climatology. The present time is one of rapid accumulation of new knowledge of the earth's rotation. Recent analyses of the Viking spacecraft signals extending over six years show that the orbits of Mars and Earth are not expanding in response to a decreasing gravitational constant at a very sensitive level. Consequently, Newton could improve his final analysis by setting the time derivative of the gravitational constant equal to zero.

REFERENCES

[1] R. R. Newton, *The Crime of Claudius Ptolemy,* The Johns Hopkins University Press, Baltimore and London (1977).

[2] C. Ptolemy, *Ptolemy's Almagest,* G. J. Toomer, ed. and trans., Springer Verlag, New York (1984).

[3] P. Muller and F. R. Stephenson, in *Growth Rhythms and the History of the Earth's Rotation,* C. D. Rosenberg and K. Runcorn, eds., Wiley, London (1975).

[4] F. R. Stephenson, in *Tidal Friction and the Earth's Rotation,* P. Brosche and J. Sundermann, eds., Springer Verlag, Berlin (1978).

[5] K. Lambeck, *The Earth's Variable Rotation,* Cambridge University Press (1980).

[6] J. K. Fotheringham, "A Solution of Ancient Eclipses of the Sun," *Mon. Not. R. Astron. Soc.* **81,** 104 (1920).

[7] T. von Oppolzer, *Cannon der Finsternisse,* Vienna (1887).

[8] E. O. Parsons, *The Alexandrian Library,* Elsevier, Amsterdam (1952).

[9] O. Pedersen, *A Survey of the Almagest,* Odense University Press, Odense, Denmark, p. 371 (1974).

[10] D. Rawlins, "An Investigation of the Ancient Star Catalog," *Publ. Astron. Soc. Pac.* **94,** 359 (1982).

[11] O. Gingerich, "Was Ptolemy a Fraud?," *Q. J. R. Astron. Soc.* **21,** 388 (1980) and **22,** 40 (1981).