CANON OF ECLIPSES

(Canon der Finsternisse)

By

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With a Preface by

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CANON

DER

FINSTERNISSE

VON

HOFRATH PROF. TH. RITTER v. OPPOLZER,

WIRKLICHEM MITGLIEDE DER KAISERLICHEN AKADEMIE DER WISSENSCHAFTEN.

HERAUSGEGEBEN VON DER

MATHEMATISCH-NATURWISSENSCHAFTLICHEN CLASSE

DER

KAISERLICHEN AKADEMIE DER WISSENSCHAFTEN

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LII. BAND IHRER DENKSCHRIFTEN.

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AUS DER KAISERLICH-KÖNIGLICHEN HOF- UND STAATSDRUCKEREI.

IN COMMISSION BEI KARL GEROLD'S SOHN,

BUCHHÄNDLER DER KAISERLICHEN AKADEMIE DER WISSENSCHAFTEN.

1887.

Preface to the Dover Edition

Three-quarters of a century have fully justified the hopes of Professor Theodor Ritter von Oppolzer that his *Canon der Finsternisse* would be a "work of lasting value for science." This tabulation of 8,000 solar and 5,200 lunar eclipses has become an unsurpassed reference for astronomers and historians alike. Although numerous eclipses have been examined with greater accuracy, no similar series of computations has been undertaken on such a grand and comprehensive scale.

Important works by two of Prof. Oppolzer's associates have extended the details of certain parts of the *Canon*. A memoir by Eduard Mahler, "Die centralen Sonnenfinsternisse des 20. Jahrhunderts" (in the *Denkschriften* of the Vienna Academy, Vol. 49, Part 2, p. 239, 1885), presented more exact paths of the central eclipses of the twentieth century, but without maps. In a monograph entitled *Spezieller Kanon der Sonnen- und Mondfinsternisse* (Berlin, 1899), F. K. Ginzel collected, from classical authors, a great number of passages which supposedly referred to eclipses of the sun and moon, and in several cases was able to associate an eclipse with the ancient description. In addition to his historical researches, Ginzel included improved calculations and maps of paths of central eclipses that had been visible in lands of classical antiquity from 900 B.C. to A.D. 500. Later J. F. Schroeter extended these calculations in *Spezieller Kanon der Zentralen Sonnen- und Mondfinsternisse, welche innerhalb des Zeitraums von* 600 *bis* 1800 *n. Chr. in Europa sichtbar waren* (Kristiania, 1923), and P. V. Neugebauer presented computations for the earlier eclipses in "Spezieller Kanon der Sonnenfinsternisse für Vorderasien und Ägypten für die Zeit von 900 v. Chr. bis 4200 v. Chr." (*Astronomische Abhandlungen*, Vol. 8, No. 4, 1931).

During the preparation of the *Canon* itself, increasing evidence indicated that the observed paths of ancient eclipses disagreed with computed positions. The considerable time span between the earliest recorded eclipses and the present day made a powerful tool available for examining the theory of the moon's motion. As early as 1786, Laplace had pointed out that the gradual diminution in the eccentricity of the earth's orbit would cause the moon to speed up. J. C. Adams recognized in 1853 that this secular acceleration would amount to 6″ in longitude per century. The eclipses calculated for the *Canon* from 1207 B.C. revealed an advance somewhat greater than that predicted by theory. Attempts to allow for the effects of missing terms in the theory of lunar motion were only partially successful, as Prof. Oppolzer realized. As a result, the errors in the tables and charts increase as one works back into antiquity and therefore the *Canon* must be used with caution for ancient eclipses. According to P. V. Neugebauer, the error in time amounts to twenty minutes around 700 B.C. and the actual curves may differ considerably from those on the charts. Less approximate paths for ancient eclipses can be computed with the tables in Neugebauer's *Astronomische Chronologie* (Berlin, 1929). In spite of its limitations, the *Canon der Finsternisse* has contributed fundamentally to the resolution of the discrepancy between theory and observation.

In 1920, study of eleven ancient eclipses identified by Ginzel and others led John K. Fotheringham, a classicist turned astronomer, to a precise value for the decrease in the moon's period of revolution (*Monthly Notices*, Vol. 81, p. 104, 1920). He found the secular acceleration of the moon to be 10″.8 in longitude per century, and that of the sun, 1″.5 per century. The retardation of the earth's rotation causes this latter effect, with a corresponding lengthening of the day by 160 microseconds per century. The slowing of the earth's rotation must also produce an apparent acceleration of the moon 13.4 times that of the sun (owing to the ratio of mean motions). To this apparent acceleration of 20″ should be added 6″, the result of J. C. Adams' gravitational theory. Thus, a total predicted secular acceleration from the two effects yields 26″ in longitude per century. Since the observed value is about 11″, a discrepancy of 15″, representing a secular retardation in the moon's motion, must be attributed to other phenomena. Presumably tidal friction is the major cause. These studies of the dynamics of the earth–moon system constitute the most important astronomical achievement made possible by the *Canon der Finsternisse*. (For a recent discussion of this problem, see Munk and McDonald, *The Rotation of the Earth* (Cambridge, 1960). See also "The Secular Acceleration of the Moon's Mean Motion" in Brown, *An Introductory Treatise on the Lunar Theory* (Dover reprint, 1960).)

A table of solar eclipses investigated by Fotheringham follows. Each eclipse is preceded by its number in the *Canon*.

Nr.	*Name*	*Date*
358	Eclipse of Babylon	−1062 July 31
1042	Eclipse of Nineveh	−762 June 15
1328	Eclipse of Archilochus	−647 April 6

Nr.	*Name*	*Date*
1489	Eclipse of Thales	−584 May 28
1795	Eclipse of Pindar	−462 April 30
1873	Eclipse of Thucydides	−430 August 3
2149	Eclipse of Agathocles	−309 August 15
2566	Eclipse of Hipparchus	−128 November 20
2957	Eclipse of Phlegon	+29 November 24
3061	Eclipse of Plutarch	+71 March 20
3738	Eclipse of Theon	+364 June 16

Of these eclipses, the two best known are the one allegedly predicted by Thales, and the one described in Amos 8:9, at Nineveh. Undoubtedly, the most famous lunar eclipse—of which Thucydides wrote a detailed account—occurred on August 27, 412 B.C. (1228 in the *Canon*).

Detailed calculations of modern eclipses, as found in the national "nautical almanacs," are generally computed by the method of F. W. Bessel. Prof. Oppolzer adopted an alternative method devised by P. A. Hansen. The two systems have certain geometric constructions in common. Both use the line passing through the center of the sun and moon for a fundamental reference axis, and a fundamental plane, perpendicular to the axis, passes through the center of the earth. In Hansen's method the X axis in this plane is parallel with the ecliptic, while in Bessel's it is parallel with the equator. *The Explanatory Supplement to the Astronomical Ephemeris and The American Ephemeris and Nautical Almanac* (London, 1960), prepared jointly by the Nautical Almanac Offices of the United Kingdom and the United States, fully describes Bessel's method as it appears in the almanac calculations. An older form is presented in Chauvenet's *Spherical and Practical Astronomy* (Dover reprint, 1960).

A comparison of a modern eclipse path from a national almanac with the charts in this volume will show the degree of accuracy of these charts. Three, and occasionally four, precisely computed points have been plotted on the azimuthal equidistant projection to define the general location of the central eclipse path. A circular arc has been drawn through the computed points, and gives a good but not exact approximation to the true path. For example, the eclipse of July 20, 1963, will actually cross the state of Maine, but on Chart No. 152 no part of the path lies within the contiguous area of the United States. This deviation occurs principally because the earth rotates during the eclipse; the path, therefore, does not fall in a small circle. Thus an eclipse will not necessarily be total at the place indicated on the chart, although the correct path can be readily computed from the tables.

The Introduction indicates that the eclipses of the moon are computed with less accuracy than those of the sun. Some lunar eclipses listed as total may be partial according to modern computations, and vice versa. The eclipse of August 26, 1961, is an example of the former possibility. Furthermore, penumbral lunar eclipses, in which only the outer shadow of the earth strikes the moon, are here disregarded. Alexander Pogo has published a list of 35 lunar eclipses included in the *Canon* that may be only penumbral, and also a list of 34 umbral, or possibly umbral, eclipses not included (*Astronomical Journal*, Vol. 47, p. 45, 1938).

A thorough analysis of the cyclical nature of the eclipses in the *Canon* has been undertaken by G. van den Bergh in his *Periodicity and Variation of Solar (and Lunar) Eclipses* (Haarlem, 1955). The *Canon* provides an excellent illustration of the well-known saros cycle of 18 years 10⅓ days, which Oppolzer employed as the basis for the computation. Dr. van den Bergh has shown that as a consequence of using the saros cycle, Oppolzer inadvertently omitted five partial solar eclipses of the 14th century. The eclipse No. 5880 (November 28, 1258) was apparently the last of its series, but after two or three saros periods another short group of unimportant polar eclipses took place. In addition, Dr. van den Bergh found five related lunar eclipses that had been omitted from the *Canon*. The relative shift of the moon's node, which Prof. Oppolzer had not taken into account, caused this unusual phenomenon.

In spite of minor defects and the improvement of lunar theory, the *Canon der Finsternisse* has remained the standard authority for eclipses, past and future. The book is all the more useful because the author, several decades prior to its general adoption by astronomers, had the foresight to employ Universal Time based on the Greenwich meridian.

Unfortunately, the *Canon* has long been out of print. We hope that this unabridged reprint, together with the English translation, will make the *Canon of Eclipses* available to all those interested in the fascinating celestial phenomenon of eclipses.

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April 1961

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Five Millennium (-1999 to +3000) Canon of Solar Eclipses Database. During the 5,000-year period from -1999 to +3000 (2000 BCE to 3000 CE), Earth will experience 11,898 eclipses of the Sun. The statistical distribution of eclipse types for this interval is as follows : 4,200 partial eclipses, 3,956 annular eclipses, 3,173 total eclipses and 569 hybrid eclipses. All the data accessed through this interface is provided by Fred Espenak and Jean Meeus (NASA Technical Publication TP-2006-214141).