

III. 7 LONG-TERM VARIATION IN THE MOTIONS OF THE EARTH AND THE MOON

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Of the three sidereally defined periods—the year, the lunar month, and the day—the year is the most stable in terms of modern methods of time-keeping such as atomic time based on molecular or electron-tilting oscillations. Its slight long-term variation is irrelevant for Egyptian chronology, because the artificial 365.0-day civil year, which was kept through all epochs, would always yield an unambiguous number of days elapsed between any two historical dates of relative chronology.

This is far from true for the lunar month and the day: The number of days elapsed between any pair of the same moon phases many centuries apart is affected by two long-term variations. The slowing of the earth's rotation over time must be studied with the greatest possible care, both empirically, using historical astronomical data gathered from non-Egyptian records, and theoretically, by calculating its physical cause (the amount of kinetic energy released from rotational momentum and transformed into heat by tidal friction). Thanks to Stephenson's recent extensive work¹ we now know that the actual number of days elapsed from any OK date until today differs by just under one day from what it would have been if the velocity of the earth's rotation remained constant.²

Long-term variation in the orbiting period of the moon has essentially the same physical cause: the slowing of the earth's rotation means a decrease in angular momentum, which the motion of the body exerting the causing force, i.e. the moon, must compensate by acceleration. The total number of lunar months elapsed between any OK date and today differs from the number they would have amounted to without such an acceleration by roughly one hundredth of a month.³

¹ Stephenson, *Eclipses*.

² Ibidem, Figs. 1.6, 2.1, 14.1, 14.2.

³ Ibidem, § 2.6.2.

Since both differences result from an integration over time of a linear effect, each increases quadratically with respect to the time elapsed. Moving back in time from today towards the OK, the result reduces, e.g., to one fourth if we move back halfway.

Relevant Peculiarities of the Motion of the Moon

There are also periodic short-term variations in lunar motion. One of them arises from the elliptic shape of its orbit and the dynamical consequences implied which results in variations in speed.

Since the sun appears, simply spoken in the ancient way, to move through exactly 12 zodiacal signs in the course of a year, and since there are 12 (exceptionally 13) new moons within this same period, the sign in which a new moon is seen from earth is the one adjacent (to the *left* as seen from northern latitudes) to the sign where the preceding new moon was seen.

Thus every month the breadth of roughly one sign is covered twice by the moon moving through the zodiac; if the moon happens to be in that part of its orbit where its speed is smallest (both absolute and apparent-angular), the month will be considerably longer than average. Such minimum speed occurs near apogee (απο γην, “away from the earth”), the point on the elliptic orbit most distant from the earth. Since Ptolemy noted the effect of this variable velocity on the position of the moon (or a planet), the phenomenon has been called “the anomaly” (αν-ομαλος, “uneven”).⁴ Calculating the anomaly in the case of the moon’s orbit is a complex procedure, because it is considerably perturbed dynamically by the gravity of a third body (the sun); however, this perturbation is negligible in the case of a planetary orbital ellipse. The perturbation in the moon’s case is the reason why the apogee is *spatially* (more exactly: *sidereally*) not always on the same side of the earth, but moves slowly around it, completing a full cycle in roughly 9 years, a fact which has been termed apsidal motion (αψις, “apse” (of the ellipse) since Hipparchus.

The fact that the beginning of an Egyptian lunar month depended on the observation of last visibility of the waning moon at dawn must also be taken into account. Unlike all other effects considered above,

⁴ Ptolemy, *Almagest*, § IV 2, Edition Heiberg (Leipzig, 1898), 269.

the success of such an observation depended not only on the lunar coordinate measured *along* the ecliptic, but also *at right angles* to it, i.e. on the ecliptical latitude. Egypt's geographic position, which is to the *north* of the equator, favours observation of the moon if it is situated *north* of the ecliptic, by contrast to a symmetrical position south of it, especially for marginal situations which always occur near the horizon.⁵

The orbit of the moon is inclined against the ecliptic by roughly 5° , so that the moon crosses it twice every month at points called the nodes. Like the apogee, these nodes are not fixed, but they revolve around the earth in a cycle of roughly 18 years.

The position of the moon near a node is crucial for the occurrence of an eclipse; both solar and lunar eclipses are relevant for the chronology of most ancient civilizations, but, exceptionally, not for Egypt. Oddly enough, there are very few, if indeed any reports of eclipses from Egypt. For that reason, eclipse theory need not be included here.

⁵ Ibidem, Heiberg, 270.