EARLY ECLIPSES OF THE GALILEAN SATELLITES*

JAY H. LIESKE**
Astronomisches Rechen-Institut, Mönchhofstrasse 12–14, D-6900 Heidelberg, F.R.G.

Abstract. A brief summary of the development of the theory of motion of the Galilean satellites is presented. Over 7700 eclipse observations have been collected and reduced using the Ephemeris E–2. They are of great potential in improving the ephemerides of the satellites and can yield important information on the evolution of the Galilean system.

1. Introduction

As outlined in a series of papers (Lieske, 1973, 1974, 1975, 1977; hereafter called Papers I–IV), the theories of motion of Jupiter’s Galilean satellites were developed by use of computerized algebraic manipulations, using the coordinate system and differential equations employed by Sampson (1921). The algebraic manipulation software was based upon the methods outlined by Broucke and Garthwaite (1969). In the final theory, the Poisson series are given as a function of 28 polynomial variables and 22 trigonometric variables, although during the development of the theory a system employing 73 polynomial and 28 trigonometric arguments was necessary before eliminating the auxiliary parameters. The 49 parameters specifying the final theory (the 50th parameter is redundant since the mean longitude of Satellite III is a function of those of Satellites I and II) may be assigned any arbitrary numerical values. Hence, the arbitrary constants can easily be altered, and ephemerides can be produced which depend upon various observational data sets (Papers V and VII (Lieske, 1978, 1980) give details of the so-called E-1 and E-2 ephemerides). The theory is a combination of numerical and analytical methods and hence contains the convergence properties of numerical development while retaining the generality of an analytic theory.

In constructing the theory, the series to be manipulated are of the form

\[ \sum C_{\theta} \sin \theta \]

where

\[ C = C_{ij} \prod_{k=1}^{28} e^{i\theta_k} = C_{i_1,i_2,\ldots,i_{28},j_1,j_2,\ldots,j_{28}} e^{i_1\theta_1} e^{i_2\theta_2} \ldots e^{i_{28}\theta_{28}} \]


** Presently a recipient of the Humboldt Award of the Alexander von Humboldt Foundation at the Astronomisches Rechen-Institut in Heidelberg and on leave from the Jet Propulsion Laboratory.
with $C_{i;j}$ being a numerical coefficient and $e_k$ being a literal quantity with $0 \leq i_k \leq 3$. The angle $\Theta$ is defined as

$$\Theta = \sum_{l=1}^{22} j_l \theta_{l} = j_1 \theta_1 + j_2 \theta_2 + \ldots + j_{22} \theta_{22}.$$  \hspace{1cm} (3)

The meaning of the parameters $e_k, \Theta_k$ are given in Paper IV.

In developing the differential equations to be integrated analytically, we employ rejection criteria (see Paper IV) in the series manipulation programs which 'look ahead' for the maximum integration factors which can occur and then only delete terms from the series if the term in the product series multiplied by the largest integrating factor is less than the rejection limit. In so doing we retain small terms in the development which will grow upon integration, but do not overburden ourselves with terms which never amount to a significant level.

The final theory presented in Paper IV has been coded into a series of computer programs which produce ephemerides and partial derivatives for arbitrary input values of the 49 parameters. A preliminary analysis of eclipses (Paper V) from 1878 to 1903 produced the so-called Ephemeris E-1, while analysis of eclipses from 1878 to 1974, mutual events in 1973, and photographic observations from 1967 to 1978 (Paper VII) resulted in Ephemeris E-2, which was employed with great success in the Voyager space mission.

2. Old Eclipses

Based upon the success with which the E-2 ephemeris could handle the Voyager encounters as well as the approximately 100-year span of eclipse observations employed in E-2, we investigated the value of older eclipse observations. It appears that an old visual observation of an eclipse is just as accurate as a modern one. In the early days the primary difficulty dealt with clocks (measurements were usually made in apparent time), whereas modern observations are limited not by clocks but by Jupiter's atmosphere and telescope-related problems. The net result is that both early and late observations are accurate to about 30 sec of time (i.e., approximately 500 km in position). Hence, early observations could be quite valuable—not only from the historical viewpoint but also for modern dynamical astronomy.

Utilizing the excellent series of eclipse observations collected by Pierce (1974) we have a nearly complete collection of eclipse observations after 1840. The great collection of over 6000 eclipses, gathered by Delambre (1817) and spanning the 17th and 18th centuries, has for the most part, apparently been lost. Sampson (1910) was able to locate the 'computer records' (i.e., the personal calculations made by Delambre's human computers) and publish approximately 1600 of the Delambre collection dealing with Satellites II and IV, but the others have never been found. The Delambre collection for Satellite II seem to the quite uniform and valuable, but those for Satellite IV are not as useful because no information is available as to where