Lunar Ephemerides, Relativity, and Lunar Laser Ranging

X X Newhall, J. G. Williams, E. M. Standish, Jr., and J. 0. Dickey
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109-8099
Phone: (818) 354-0000 Fax: (818) 393-6890 E-mail: xxn@logos.jpl.nasa.gov

From 1969 through 1972, lunar space missions placed four functioning laser retroreflector arrays on the Moon. Several observatories have ranged the reflectors from 1969 to the present. Beginning in March, 1970, ranging data were accurate enough to be used for parameter estimation. Approximately 9700 normal points have been acquired from three observatories over the past 25 years, with accuracies over the past five years being 2-3 cm.

The implementation of lunar laser ranging (LLR) ushered in a new era of lunar ephemerides and determination of values of parameters of General Relativity. After only eight years of ranging data acquisition, the ephemeris accuracy improved by three orders of magnitude and obviated the need for any other data type. In addition, ranging data arc sufficiently accurate to permit the estimation, modelling, and integration of the lunar physical libations.

Several parameters of General Relativity have been estimated, including (1) the PPN parameters β and γ, (2) the rate of change of the gravitational constant G, (3) the departure of geodetic precession from the prediction of General Relativity, and (4) the validity of the Principle of Equivalence.

JPL has recently generated the lunar and planetary ephemeris DE403. This paper discusses the modelling, numerical integration, and polynomial representation of the ephemeris. A significant recent modelling improvement is the lunar elastic dissipation. This feature requires the implementation of retarded-time differential equations, which, when integrated backward, function mathematically as advanced-time equations.

Also given are the results of the Relativity parameter estimation and a comparison of DE403 with earlier JPL ephemerides, notably DE102 (produced in 1978), to illustrate the effects of a more refined physical model and of the inclusion of 17 more years of LLR data.