Modern Numerical Ephemerides of Planets and the Importance of Radar Observations for Their Creation

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The performance of complicated experiments in space and the introduction of new astrometric methods (radar ranging, lunar laser-ranging, VLBI measurements) into practice was required planetary ephemerides more precision than classical analytical theories. On the other hand, these modern data made possible creating of such ephemerides. Now the numerical integration is necessary to mach the accuracy of modern ephemerides. Numerical planetary theories were being began to construct by several groups in USA and Russia to ensure space flights in the late 1960's. The JPL's DE/LE ephemerides have been most widespread in USA and the world and series of EPM (Ephemerides of Planets and the Moon) theories have been produced at Institute of Theoretical and (later) Applied Astronomy in Russia.

Common to all DE/LE and EPM ephemerides are simultaneous numerical integrations of the equations of motion of nine planets, the Sun, the Moon and the lunar physical librations performed in the parameterized Post-Newtonian metric for the garmonic coordinates $\alpha = 0$ and General Relativity $\beta = \gamma = 1$.

The following are differences of various theories:

- the modeling of the lunar librations,
- the modeling of the perturbations of asteroids upon the planetary orbits,
- reference frames,
- the used sets of observations.

Concise characteristics of the ephemerides DE118/LE62, DE200/LE200, DE403/LE403, DE405/LE405, EPM87, EPM98, EPM99 are described. Graphical comparisons of the series of DE ephemerides between to one another and EPM ephemerides are given. A fairly good agreement of planetary orbits is between the DE403, DE405 and, respectively, EPM98, EPM99 over the interval of 120 years (1866-2006) covered EPM98 and EPM99. Maximum difference $0.''003$ for the mean longitudes was for Mars, differences for the mean longitudes of other planets were significantly below. It is explained by a slight disagreement for the dynamic models of DE403, DE405 and EPM98, EPM99 which is attributed to more correct computation of orbits of Ceres, Pallas and Vesta for the theories EPM at the present time.

At present time the orientation of ephemerides is established from VLBI observations of orbiting spacecraft, lunar ephemerides are determined from lunar laser ranging, orbits of outer planets are improved from optical data and orbits of 4 innermost planets - from radar observations. Moreover radar observations of planets make it possible to determine a broad set of astronomical constants from the value of the astronomical unit (AU) to relativistic parameters of PPN formalism. The values of astronomical constants: AU, parameters of Mars rotation, including its precessional rate (p), the masses of Jupiter, Ceres, Pallas and Vesta, relativistic parameters of PPN formalism, the variability of the gravitational constant G, obtained in the fitting process of the DE405 and EPM99 ephemerides to data totaling near 80,000 American and Russian radar observations of planets (1961-1997), the Viking and Pathfinder landers, are given. So, AU and p with theirs formal 1σ errors are:

$$AU_{DE405} = (149597870693.0 \pm 0.2)\ m,\ AU_{EPM99} = (149597870691.2 \pm 0.2)\ m,$$
$$p_{DE405} = (-7579.4 \pm 5.2)\ mas/year,\ p_{EPM99} = (-7583.4 \pm 5.2)\ mas/year.$$