Natural Satellite Ephemerides

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6 Sep 1994

Excluding the Earth's Moon, there are sixty recognized natural satellites in the Solar System. Ephemerides for most may be found in The Astronomical Almanac. In addition, the U.S. Naval Observatory produces an electronic version, The Satellite Almanac, for IBM PC's and compatibles.

Ephemerides for all sixty satellites are also being maintained at NASA's Jet Propulsion Laboratory (JPL) and are available electronically as elements of NASA's SPICE information system. The acronym refers to the logical kernels: Spacecraft ephemeris, Planet ephemeris and constants, Instrument descriptions, Camera pointing, Events. The SPICE concept was defined by planetary scientists and is being implemented by JPL's Navigation Ancillary Information Facility (NAIF). Satellite ephemerides are included as part of the SPK kernel and are in the form of a Spacecraft-Planet Kernel (SPK) file.

For Phobos and Deimos the ephemerides in the Astronomical Almanac are based on the theory of Sinclair (1972, 1989). The theory of Struve (1911) modified by Born and Duxbury (1975) and Hildebrand *et al.* (1979) and later updated by Jacobson *et al.* (1989) was used at JPL. It is being replaced by Sinclair's theory as extended by Morley (1990). The high accuracy ESAPHO and ESADE theories developed by Chapront-Touzé (1988, 1990a, 1990b) are also in use at JPL.

The theory for Jupiter's Galilean satellites was developed by Sampson (1921) and later revitalized by Lieske (1977). The Astronomical Almanac ephemerides are based on this theory with the values of the theory constants from Arlot (1982). The theory is also used for the JPL ephemerides but with the updated constants from Lieske (1994).

The orbits of the outer Jovian satellites are represented by numerical integration. The Astronomical Almanac ephemerides are integrated from the initial conditions of Rohde (1979), and the JPL ephemerides use the initial conditions of Jacobson (1994).

The ephemerides for the Saturnian satellites in Astronomical Almanac are based on analytical theories. For Mimas, Enceladus, Tethys and Dione the theory is that of Kozai (1957) with updates from Garcia (1972) and Taylor and Shen (1988). For Rhea and Titan the theory of Sinclair (1977) with updates from Garcia (1972) and Taylor and Shen (1988) is used. The Hyperion theory is due to Taylor (1984), and the Iapetus theory is from Sinclair (1974) with updates from Harper *et al.* (1988) and Taylor and Shen (1988). The theory of Zadunaisky (1954) is used for

Pho ['1)('. At JPL the ephemerides are all based (in the numerical integration done by Jacobson and Vaughan (1993).

Both the Astronomical Almanac and JPL have ephemerides for the major Uranian satellites based on the theory developed by Laskar (1986) and fit to observations by Laskar and Jacobson (1987). In addition, Jacobson *et al.* (1986) nil\'{' produced numerically integrated ephemerides.

The Astronomical Almanac uses analytical theories for the ephemerides of Triton and Nereid. The theory for Triton is from Harris (1984) and for Nereid is from Mignard (1981). At JPL the ephemerides for both satellites are the result of numerical integration fit to observations by Jacobson *et al.* (1991).

The orbit of Charon is modeled as a two body conic orbit with elements determined by a fit to observations. The Astronomical Almanac ephemeris uses elements from Tholen (1985). The J 1'1, ephemeris uses elements from Tholen (1990) with a semi-major axis from Null *et al.* (1993).

At JPL a precessing ellipse theory 1('1)1(w'tit); of the orbits of the remaining minor satellites. For the four inner Jovian satellites the precessing ellipse elements are from Synnott (1982, 1984). For the nine minor satellites of Saturn the elements are from Synnott (1981, 1983) and Showalter (1991). The elements of the ten minor Uranian satellites are from Owen and Synnott (1987) and for the six minor Neptunian satellites are from Owen *et al.* (1991). The Astronomical Almanac ephemeris for Amalthea is based on the work of Van Woerkom (1950) and for Thebe is based on the precessing ellipse with Synnott's (1984) elements. Astronomical Almanac does not have ephemerides for the remaining minor satellites.

Table 1 summarizes the ephemerides and their sources.

Acknowledgements

This research was ('iII" Ii('(I out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Table 1

Available Satellite Ephemerides

Satellites	Astron. Almanac Source	JPL Source
Phobos & Deimos	Sinclair (1989)	Jacobson *et al.* (1989) Chapront-Touzé (1990)
Galileans	Arlot (1982)	Lieske (1994)
Amalthea	Van Woerkom (1950)	Synnott (1982)
Thebe	Synnott (1984)	Synnott (1984)
Adrastea & Metis		Synnott (1984)
Outer Jovians	Rohde† (1990)	Jacobson† (1994)
Major Saturnians	Kozai (1957) Garcia (1972) Taylor & Shen (1988)	Jacobson & Vaughan† (1993)
Hyperion	Taylor (1984)	Jacobson & Vaughan† (1993)
Phoebe	Zadunaisky (1954)	Jacobson & Vaughan† (1993)
Inner Saturnians		Synnott *et al.* (1981) Synnott *et al.* (1983)
Pan		Showalter (1991)
Major Uranians	Laskar & Jacobson (1987)	Laskar & Jacobson (1987) Jacobson *et al.* (1986)
Inner Uranians		Owen & Synnott (1987)
Triton	Harris (1984)	Jacobson *et al.*† (1991)
Nereid	Mignard (1981)	Jacobson *et al.*† (1991)
Inner Neptunians		Owen *et al.* (1991)
Charon	Tholen (1985)	Tholen (1990)

† Numerically integrated