NEW CONSTANTS FOR SAMPSON-LIESKE THEORY OF THE GALILEAN SATELLITES OF JUPITER FROM MUTUAL OCCULTATION DATA

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Abstract. New constants for Sampson-Lieske theory of the Galilean Satellites have been derived using 6360 individual photographic positions (1891-1990) and 438 pseudo astrometric positions from mutual occultations during 1973, 1979, 1985 and 1991. Using these new sets of constants, significant improvement is noticed in the O-C values of the sky plane coordinates of the mutual event data set and residuals in longitude for Io and Europa are found to improve. Problems concerning the inclusion of mutual event data in attempting evaluation of secular variations of the mean motions of the satellites are discussed.

1. Introduction

The constants of motion of the Galilean Satellites are efficiently updated using Lieske's (1974, 1977) technique by computing the corrections (ε, β) to the basic sets of constants. Lieske progressively updated these constants from E1 (Lieske, 1978), using the eclipse data of 1878-1903, to E2 (Lieske, 1980), by supplementing visual eclipses between 1903 and 1972, photographic data between 1967 and 1978 and mutual events of 1973. The E2x3 (Lieske, 1987) ephemeris was derived by further additions of more mutual event pairs from 1973 and 1979, 183 pairs of data from Voyager optical navigation images and 15711 classical eclipses from 1652-1983. Arlot (1982)

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used 8856 individual photographic observations between 1891 to 1978 to derive the G5 ephemeris. The present investigations relate to determinations of new sets of constants using photographic data between 1891 to 1990 and astrometric positions derived from mutual occultations during 1973, 1979, 1985 and 1991.

2. The observational material

Most of the photographic data that were used by Arlot(1982) were utilized in this study. Additional excellent unpublished photographic material covering the period between 1986 and 1990 (Pascu, private communication) have been included. Table 1 gives the details of the observations and includes the mutual occultation data set containing the astrometric positions derived from the mutual occultation light curves of 1985 and 1991 assuming Hapke's light scattering law for a macroscopically rough surface (Hapke, 1984), using the Hapke's parameters derived by Descamps and Thuillot (1993). The published positions of the 1985 series by the Galilean Satellite Observers (GSO and Franklin, 1991), which were derived using Lambert's law, were reconstructed to adopt Hapke's law and included in our studies (Vasundhara, 1993 and 1994). Published positions of 1973 (Aksnes and Franklin 1976) and 1979 (Aksnes et al. 1984) were also used after accounting for the phase corrections (Aksnes, Franklin and Magnusson 1986). Table 1 gives the statistics for all the data that we used.

3. Corrections to the constants

The method developed by Arlot(1982) has been used in the present study. The starting ephemeris was E1 (Lieske 1987) and 3 more iterations were carried out by progressively adjusting the (ϵ, β) values. The constants that were updated were the mean motions $(\epsilon_6 - \epsilon_8)$, the primary eccentricities $(\epsilon_{16} - \epsilon_{19})$, the primary sine inclinations $(\epsilon_{21} - \epsilon_{24})$, the mean longitudes $(\beta_1, \beta_2, \beta_4)$, the proper perijoves $(\beta_6 - \beta_9)$, the proper nodes $(\beta_{11} - \beta_{14})$, the libration amplitude (ϵ_9) and the libration phase angle (β_5).

Let us remind that the G5 ephemeris was based only on photographic observations from 1891 to 1978. By adding the recent photographic data made from 1986 to 1990 (Pascu, private communication) and the mutual occultations data (see table 1) with a weight of 50, we obtained the ephemeris I32, and I33 using a weight of 10. The ephemeris G6 was constructed using only the photographic data of Table 1 and the updated ε and β values for Jupiter related constants and mass of the satellites introduced by Lieske (1987) in his E2x3 ephemerides. The values of the constants for all these ephemerides are available using FTP anonymous on

TABLE 1. Details on the data

Observers	Codes[1]	Year	No. of positions				r.m.s. of the residuals (arcsec)			
			J1	J2	J3	J4	G5	G6	I32	I33
Renz	H,P	1891-1898	171	175	184	174	0.117	0.111	0.110	0.111
Balanovsky	P	1904-1910								
Chevalier	Zo-Se	1917/1918	132	132	133	121	0.148	0.150	0.151	0.151
De Sitter	G	1918/1919								
De Sitter	C	1924								
Petrescu	B	1934	85	104	106	118	0.217	0.222	0.223	0.222
Petrescu	P	1936								
Van Biesbr.	Y	1961-1963								
Gorel	N	1962-1966								
Soulié	Bo	1966-1974	284	282	318	307	0.390	0.390	0.390	0.390
Gorel	N	1973-1974								
Debehogne	RJ,U,LS	1977/1978								
Ianna et al.	Mc-C	1977/1978	70	100	95	108	0.104	0.104	0.104	0.104
Pascu	Mc-C	1967/1968	88	87	89	95	0.095	0.095	0.095	0.095
"	USNO	1973	72	65	62	67	0.111	0.110	0.111	0.111
"	"	1974	107	115	120	123	0.082	0.085	0.085	0.085
"	"	1975-1977	107	116	109	119	0.085	0.086	0.086	0.086
"	"	1977/1978	59	59	53	59	0.102	0.103	0.103	0.103
Pascu[2]	"	1986	84	74	82	80	0.077	0.074	0.074	0.074
"	"	1987	116	133	129	133	0.074	0.070	0.071	0.071
"	"	1988/1989	52	54	60	60	0.059	0.056	0.056	0.056
"	"	1990	79	72	84	96	0.068	0.066	0.067	0.067
AkFr[3]	-	1973	45	48	3	0	0.017	0.014	0.014	0.014
Ak[4]	-	1979	4	7	3	0	0.010	0.014	0.011	0.011
Ar[5],GSOF[6]	-	1985	59	62	73	26	0.024	0.024	0.024	0.024
Ar[7]	-	1991	45	53	9	1	0.036	0.024	0.028	0.030

1. Observatory codes. H:Helsingfors, P:Pulkovo,G:Greenwich C:The Cape, P:Paris, Y:Yerkes, N:Nicolaiev, Bo:Bordeaux, RJ:Rio de Janeiro, U:Uccle, B:Bucarest, LS:La Silla, Mc-C:Mc Cormick, USNO:U.S. Naval Observatory, Washington D.C.
2. Private communication
3. Aksnes and Franklin, 1976
4. Aksnes et al., 1984
5. Arlot et al., 1992
6. GSO and Franklin, 1991
7. Arlot et al., 1996

TABLE 2. Error in Longitude (minutes of time)

Data set	J1	J2	J3	J4	Ephem.
Ph	0.060 ± 0.011	0.009 ± 0.012	0.053 ± 0.015	0.073 ± 0.020	G5
Ph+ME	0.058 ± 0.010	−0.021 ± 0.011	0.041 ± 0.014	0.076 ± 0.019	G5
Ph	0.019 ± 0.011	0.038 ± 0.012	0.058 ± 0.015	0.207 ± 0.020	G6
Ph+ME	0.019 ± 0.010	0.038 ± 0.012	0.058 ± 0.015	0.207 ± 0.019	G6
Ph	0.019 ± 0.011	0.039 ± 0.012	0.078 ± 0.015	0.201 ± 0.020	I32
Ph+ME	0.018 ± 0.010	0.017 ± 0.011	0.067 ± 0.014	0.203 ± 0.019	I32
Ph	0.021 ± 0.011	0.040 ± 0.012	0.059 ± 0.015	0.204 ± 0.020	I33
Ph+ME	0.021 ± 0.010	0.039 ± 0.012	0.059 ± 0.014	0.205 ± 0.019	I33
Ph+ME	1508	1568	1624	1660	data points
Ph+ME	1508 + 153	1568 + 170	1624 + 88	1660 + 27	data points

TABLE 3. Secular accelerations of the Galilean satellites J1, J2, J3 in $\dot{n}/n \times 10^{11} \mathrm{yr}^{-1}$ units

Authors	J1	J2	J3
De Sitter (1928)	25	27	−16
Brouwer & Clemence (1961)	32	27	16
Greenberg (1986)	32 ± 8	−16 ± 4.5	−16 ± 4.5
Lieske (1987)	−0.74 ± 0.87	−0.82 ± 0.97	−0.98 ± 1.53
Goldstein (1996a)	45.4 ± 9.5	-	-
Goldstein (1996b)	70 ± 75	56 ± 57	28 ± 20
This paper/G5	24.6 ± 7.3	−12.7 ± 8.4	−0.22 ± 10.7
This paper/I32	22.7 ± 7.9	−6.1 ± 9.3	+10.6 ± 10.6

ftp.bdl.fr/pub/ephem/satel/theories or may be sent upon request near the authors.

4. Results and discussion

The r.m.s. of the residuals (table 1) shows a small improvement after using the mutual occultations data to fit the theory. More, it is remarkable that G6, which is fitted only on photographic data, shows very small residuals for the mutual occultations data. In any case, these data are of high accuracy. In table 2, we tried to determine a longitude shift from the residuals after different fits of the theory. This shift may be interpreted either as an error on the longitude at the origin of time, or as an error on the mean motion. It is puzzling to see that this error is decreasing when including recent observations to fit the theory (G6, I32, I33) for J1, stable for J3 but increasing slightly for J2 and much more for J4. On the other hand, the comparison between G6 and I32 shows that the mutual occultations data do not improve the ephemeris more than the photographic data for the period 1986-1993. This could be explained by the larger number of photographic data (1388 points) than the one of mutual occultations data (328 points). Table 3 gives the secular accelerations calculated from the residuals of all the data presented in table 1 calculated using G5 and I32. Our results are significant only for J1. Note that the methods of calculations of the other authors are completely different and that we give their data only to appreciate the scale of values of these accelerations.

In conclusion, the residuals of the mutual occultations data look very good but these data are not yet sufficient to improve the ephemerides. We look forward to using data from mutual eclipses and from the forthcoming mutual event opportunity in 1997.

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