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AN ANALYSIS OF THE 1985 OBSERVATIONS OF MUTUAL PHENOMENA OF THE *GALILEAN SATELLITES*

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ABSTRACT

This paper derives midtimes and relative satellite positions from nearly 200 light curves of mutual eclipses and occultations of the *Galilean satellites* that occurred in 1985. We show that, at least for observations of the highest quality, the standard errors on the midtimes are smaller than 1 s and close to 0.01 arcsec. on the positional offsets in right ascension and declination.

This paper presents astrometric results obtained from 198 light curves of 105 mutual eclipses and occultations of the *Galilean satellites* observed during 1985. All details used in the analysis have already been discussed and applied in three earlier papers. The first of these (Aksnes & Franklin 1976; hereafter referred to as Paper I) developed the basic reduction methods and analyzed the data gathered in 1973; the second (Aksnes *et al.* 1984; hereafter referred to as Paper II) introduced some refinements and treated light curves of both the *Galilean* and *Saturnian satellites* observed in 1979–1980. Paper III (Aksnes *et al.* 1986) resolved a troublesome point by showing that phase effects were the source of certain moderate-to-small discrepancies between eclipses and occultations that had previously prevented the astrometric results from achieving the full accuracy inherent in the technique. Paper III brought matters up to date by applying the needed phase corrections to the data in Papers I and II. We have continued to observe and reduce light curves of the *Galilean satellite* events because of the high precision of their astrometry and because a body of material extending over numerous apparitions will allow, possibly in connection with results from the Galileo Mission, a modern estimate of likely changes in Io's orbit due to tidal interaction.

All quantities derived from the 1985 light curves are gathered together in Table 1. The abbreviation of the observer or observatory given in its first column can be identified either in the listing of the GSO authors on the title page or in the Acknowledgments at the end of this paper. The principal results of Table 1 are (1) the event midtimes in column 2, and (2) the separations in right ascension, $D\alpha \cos \delta$, and declination, $D\delta$, at those times. Columns 6 and 7 contain these quantities. Table 1 is therefore the near equivalent of Tables 1 and 2 in Paper II. We stress the qualifier "near equivalent" because the results compiled in that paper require phase corrections to account for the fact that the distribution of light on a satellite's surface varies substantially with solar phase angle θ. Put briefly, the "light center" of a uniform satellite coincides with its geometric center only when $\theta = 0$ deg. with the separation between the two being greatest at quadrature, $\theta \cong 11$ deg. A discussion of phase effects and an evaluation of the necessary corrections based on various scattering laws was given in Paper III, which showed (1) that the geometric and light centers of the largest satellite (*Ganymede*) could differ by slightly more than 200 km and (2) that these separations were in the opposite direction for eclipses and occultations. During our reduction of the data presented here, we again encountered the behavior produced by the phase effects that Paper III analyzed.

One has the choice of applying phase corrections either to the observed midtime or to the astrometric offsets. Table 1 of this paper deals with this problem in the following way. The UT of midevent listed in column 2 is to be regarded strictly as an observed quantity. It has been derived by fitting (in the sense of least squares) two limb darkened, "phase modified," but otherwise uniform disks with Voyager radii (Davies & Katayama 1981) to a light curve. (These radii and standard errors in km are J1: 1815 ± 5; J2: 1568 ± 10; J3: 2631 ± 10 and J4: 2400 ± 10, all within 2% of values derived from the 1973 observations in Paper I.) By "phase modified," we mean that the light distribution on the satellite disks has been altered by Lambert's law to mimic the circumstances at the time of observation. Thus these midtimes refer to the time when the light centers of the two satellites are separated by the minimum amount. The quantities appearing in columns 4–7, which we shall discuss presently, have all been corrected to apply at these midtimes. Even when phase effects made their maximum contribution,

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TABLE 1. Results from light curves of the 1985 mutual events.

OBS.	1985 UT DATE					DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	Φ_1	Φ_2	Wgt
	mo	da	hr	min	sec	sec	km	km	arcsec		deg		
The following events are J1 eclipsing J2													
SAAO	08	30	21	03	59.7	14.0	-345	-794	0.187	-0.502	64	34	2
Catn	09	07	00	29	52.1	10.0	-157	-828	0.153	-0.384	77	37	1
CTIO	09	07	00	29	42.0		-88	-719	0.143	-0.356			2
Perth	09	10	13	57	45.2	9.4	-11	-713	0.128	-0.306	81	38	2
CTIO	09	14	03	22	40.4	8.9	60	-662	0.110	-0.247			2
Oak R	09	14	03	22	42.2		44	-651	0.109	-0.244	85	39	1.5
Low'l	09	14	03	22	38.9		75	-653	0.109	-0.244			2
Mt L	09	14	03	22	42.9		37	-665	0.110	-0.247			2
Stwd	09	14	03	22	42.8		38	-674	0.111	-0.250			2
	(B Filter)												
Stwd	09	14	03	22	42.1		44	-659	0.109	-0.247			2
	(R Filter)												
ESO	(09	14	03	22	45)		18	-683	0.112	-0.252			1.5
CTIO	09	21	06	03	21.5	8.2	152	-586	0.072	-0.138	92	39	2
TL	09	21	06	03	20.6		172	-600	0.075	-0.140			2
KPNO	09	21	06	03	20.5		174	-597	0.075	-0.140			2
Low'l	09	21	06	03	20.6		172	-674	0.084	-0.159			1.5
Mt L	09	21	06	03	24.1		134	-529	0.069	-0.122			1.5
ESO	(09	21	06	03	24)		134	-616	0.076	-0.145			1.5
Nice	09	24	19	20	37.5	7.9	173	-588	0.061	-0.092	95	39	1.5
OHP1	09	24	19	20	37.0		176	-615	0.062	-0.099			1.5
OHP2	09	24	19	20	37.3		171	-648	0.065	-0.107			1.5
SAAO	10	01	21	52	06.7	7.5	288	-580	+0.027	+0.004	99	38	2
TL	10	16	02	45	20.9	7.0	464	-546	-0.048	0.217	109	37	2
Low'l	10	16	02	45	18.5		505	-533	-0.049	0.221			2
Brzl	(10	16	02	45	21)		461	-505	-0.052	0.228			1.5
Perth	10	19	15	57	18.3	6.8	654	-532	-0.070	0.277	111	36	1.5
Low'l	10	23	05	08	42.5	6.7	545	-504	-0.094	0.340	112	36	1.5
J/R	10	23	05	08	38.0		630	-465	-0.095	0.352			1.5
CI	11	02	20	41	10.5	5.7	526	-432	-0.172	0.537	118	34	2
Perth	11	13	12	10	36.3	4.0	698	-426	-0.255	0.729	123	32	2
The following events are J1 occulting J2													
Catn	09	06	21	50	51.4	-13.4	-474	-859	0.282	-0.922	61	33	1

TABLE 1. (continued)

OBS.	1985 UT DATE					DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	Φ_1	Φ_2	Wgt
							J1 occs. J2 cont'd.						
Oak R	09	14	01	04	44.6	-8.7	-211	-721	0.252	-0.873	74	37	1
ESO	09	14	01	04	44.4		-207	-746	0.255	-0.882			2
CTIO	09	14	01	04	22.5		-76	-784	0.259	-0.894	74	37	1.5
Perth	09	17	14	28	02.9	-7.9	-245	-696	0.253	-0.884	78	38	1.5
Oak R	09	21	03	48	36.9	-6.7	-124	-596	0.247	-0.875	82	38	1
ESO	(09	21	03	48	33)		-105	-820	0.273	-0.942			1
CTIO	09	21	03	48	37.2		-119	-668	0.256	-0.898			1
Catn	12	04	17	18	22.1	-3.8	804	-416	0.179	-0.598	126	30	1.5
Nice	12	04	17	18	16.4		931	-423	0.179	-0.600			1.5
Tokyo1	12	15	08	55	07.1	-3.9	921	-356	0.108	-0.371	132	28	1.5
Tokyo2	12	15	08	55	10.0		894	-329	0.108	-0.364			1.5
							The following events are J1 eclipsing J3						
SAAO	08	31	19	42	42.3	5.9	-215	120	0.269	-0.715	255	338	2
Catn	09	07	23	22	03.8	11.9	-382	46	0.212	-0.504	270	336	1
ESO	09	07	23	22	02.4		-369	51	0.211	-0.503			2
CTIO	09	07	23	22	03.5		-379	119	0.206	-0.486			2
TL	09	23	03	57	37.3	5.5	633	-179	0.382	-1.009	121	20	2
Mt L	09	23	03	57	31.4		746	-138	0.379	-0.998			1
CTIO	09	23	03	57	37.4		615	-139	0.379	-0.999			2
Low'l	09	23	03	57	38.5		606	-51	0.372	-0.976			1
KPNO	09	30	06	57	02.8	6.5	749	-77	0.316	-0.780	130	18	1.5
Tokyo	10	14	12	42	08.0	7.8	898	(10)	0.157	-0.296	146	13	1
Perth	10	21	15	30	31.7	7.7	933	-32	+0.078	-0.055	153	10	1.5
SAAO	10	28	18	16	53.9	7.4	1045	12	-0.020	+0.213	160	8	2
CI1	11	04	21	02	07.4	7.0	1034	131	-0.131	0.503	167	5	2
CI2	11	04	21	02	04.4		1107	79	-0.128	0.489			2
							The following events are J1 occulting J3						
SAAO	07	13	00	32	08.2	2.7	553	169	0.310	-0.833	202	351	2
TL	07	27	05	17	39.7	1.1	606	110	0.295	-0.858	213	347	1.5
Mt L	07	27	05	17	45.6		450	128	0.290	-0.853			1.5

TABLE 1. (continued)

OBS.	1985 UT DATE					DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	ϕ_1	ϕ_2	Wgt
J1 occs. J3 cont'd.													
TL	08	03	07	41	13.9	+0.2	448	62	0.301	-0.917	219	345	2
JW	08	03	07	41	11.9		499	40	0.303	-0.924			2
Oak R	08	03	07	41	07.4		549	78	0.300	-0.913			1.5
ESO	08	03	07	41	08.3		578	232	0.285	-0.868			1.5
Low'l	08	10	10	06	30.9	-0.8	243	167	0.296	-0.942	224	344	1.5
Mt L	08	10	10	06	23.4		432	108	0.301	-0.961			1.5
TL	08	10	10	06	29.7		291	103	0.302	-0.962			1.5
Rowe	08	17	05	34	43.2	-1.8	278	215	0.319	-0.982	230	342	1.5
Tokyo	08	17	05	34	41.1		257	42	0.315	-1.039			1.5
Tokyo	08	24	15	07	03.4	-2.9	81	145	0.308	-1.054	237	341	1.5
SAAO	08	31	17	45	58.5	-4.0	-102	168	0.306	-1.077	245	339	2
Catn	09	07	20	34	04.9	-5.6	-305	66	0.334	-1.095	253	338	1
Oak R	09	14	23	38	01.4	-8.7	-493	123	0.283	-1.048	264	337	1
ESO	09	14	23	37	43.5		-291	-25	0.299	-1.096			1
CTIO	09	14	23	37	59.3		-469	111	0.285	-1.055			2
CTIO	09	22	03	19	33.8	-17.1	-639	28	0.267	-0.998	280	337	2
Low'l	09	22	03	19	51.2		-753	75	0.261	-0.980			1
TL	09	22	03	19	33.5		-632	57	0.263	-0.986			2
ESO	09	22	03	19	40.8		-683	100	0.260	-0.977			1.5
The following event is J1 eclipsing J4													
CI	10	10	23	39	33.3	7.6	2176	-501	-0.115	+0.452	145	7	1.5
The following events are J1 occulting J4													
Brzl	(06	16	04	09	19)	5.3	2206	-394	0.355	-0.904	137	9	1
ESO	07	19	04	20	03.2	-6.6	522	-653	0.174	-0.457	16	3	1.5
Low'l	09	06	05	57	11.3	-22.3	1304	76	0.337	-1.059	286	347	1.5
	(J2 also in aperture)												
The following events are J2 eclipsing J1													
CI	10	20	23	18	08.3	4.2	1253	2	0.211	-0.473	170	16	2
Perth	10	24	12	24	54.3	4.4	1207	16	0.185	-0.395	169	17	2
Low'l	10	28	01	31	43.1	4.6	1228	78	0.155	-0.309	167	19	2
ESO	10	28	01	31	43.7		1212	37	0.159	-0.320			2

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TABLE 1. (continued)

OBS.	1985 UT DATE					DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	Φ_1	Φ_2	Wgt
							J2 ecls. J1 cont'd.						
Perth	10	31	14	38	33.6	4.7	1209	(100)	0.129	-0.234	167	20	1
Low'l	11	04	03	45	29.1	4.7	1160	151	0.098	-0.154	167	21	2
Mt. L	11	04	03	45	27.7		1228	146	0.106	-0.153			2
Catn	11	07	16	52	19.6	4.7	1214	(120)	0.056	-0.102	166	23	1
Catn	11	14	19	06	20.7	4.7	1254	(120)	+0.027	+0.036	164	25	1
Tokyo	11	25	10	27	41.3	4.6	1253	(130)	-0.048	0.223	162	29	1
							The following event is J2 occulting J3						
Tokyo	12	24	08	13	32.0	-6.8	-46	(-620)	-0.029	-0.023	218	337	1
							The following events are J2 eclipsing J4						
Mt L	09	23	03	18	21.8	8.6	1385	-524	-0.120	0.450	232	344	2
Low'l	09	23	03	18	14.9		1496	-507	-0.122	0.454	232	344	2
Perth	10	10	11	52	33.1	8.4	1564	(-700)	+0.019	0.093	189	357	1
Low'l	11	14	02	45	02.7	20.9	1436	(-490)	0.007	0.117	94	21	1
CTIO	11	14	02	44	57.4		1483	(-490)	0.006	0.117			1
TL	11	14	02	45	08.2		1395	(-490)	0.005	0.117			1
							The following events are J2 occulting J4						
SAAO	05	29	04	11	17.5	14.7	1528	(-450)	0.110	-0.148	253	340	1
Brzl	(05	29	04	11	15)		1555	(-450)	0.110	-0.146			1
ESO	05	30	10	38	06.5	-36.3	1242	(-160)	0.213	-0.419	22	8	1
TL	05	30	10	38	05.8		1252	(-160)	0.213	-0.415			1
							The following events are J3 eclipsing J1						
Oak R	09	19	02	14	56.0	3.5	976	82	0.289	-0.751	175	12	1
CTIO	09	19	02	15	02.7		789	64	0.291	-0.754			2
KPNO	09	26	04	59	55.3	4.3	751	175	0.198	-0.466	172	20	2
Low'l	09	26	04	59	52.3		833	34	0.212	-0.502			1.5
ESO	09	26	04	59	55.9		738	-28	+0.216	-0.518			1.5
Perth	10	17	13	23	25.2	5.7	786	115	-0.047	+0.239	165	42	2

TABLE 1. (continued)

OBS.	1985 UT DATE					DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	Φ_1	Φ_2	Wgt
						J3 ecls. J1 cont'd							
Oak R	11	07	22	24	50.6	8.0	463	-38	-0.225	0.733	158	69	1
CI	11	07	22	24	51.4		431	33	-0.237	0.749			1.5
Oak R	11	15	23	51	20.9	13.8	-496	(-230)	0.039	0.046	203	268	1
Low'l	11	23	03	33	28.1	9.2	-294	-199	-0.086	0.316	202	283	2
						The following events are J3 occulting J1							
Low'l	06	03	11	07	31.3	7.0	208	30	0.346	-0.869	158	69	1.5
M Kea	06	10	14	13	25.4	9.1	224	121	0.266	-0.635	157	81	2
	(L Filter; 3.8 Microns)												
M Kea	06	10	14	13	29.4		152	92	0.263	-0.646	157	81	1.5
	(M Filter; 4.8 Microns)												
Perth	06	17	17	43	27.5	12.8	-346	-13	0.224	-0.518	157	95	1
CTIO	11	22	01	14	35.9	-6.7	314	-93	0.253	-0.879	158	71	1
M Kea	11	29	04	54	19.5	-10.9	161	68	0.165	-0.599	157	86	2
	(K Filter; 2.2 Microns)												
M Kea	11	29	04	54	20.5		150	45	0.167	-0.604			1.5
	(M Filter)												
						The following events are J3 eclipsing J2							
Oak R	07	30	06	42	09.1	-1.0	134	-703	0.170	-0.518	143	73	1.5
DS	07	30	06	42	08.4		142	-680	0.166	-0.510			1.5
KPNO	07	30	06	42	10.9		109	-571	0.158	-0.485			2
Brzl	(07	30	06	42	11)		109	-666	0.165	-0.506			1.5
WA	08	06	10	20	45.2	+0.4	22	-558	0.052	-0.149	142	78	2
Rowe	08	06	10	20	41.9		61	-621	0.058	-0.165			2
Low'l	08	06	10	20	42.0		59	-596	0.056	-0.158			1.5
J/R	08	06	10	20	41.8		62	-612	0.057	-0.163			1.5
MtL	08	06	10	20	42.6		55	-569	+0.054	-0.151			1.5
WA	08	13	14	04	37.5	2.0	37	-600	-0.045	+0.152	141	82	1.5
Perth	08	13	14	04	38.1		37	-555	-0.048	0.164			2
SAAO	08	27	22	01	31.5	6.4	53	-483	-0.240	0.743	141	94	2
OHP	08	27	22	01	32.9		43	-473	-0.241	0.745			1.5
CTIO	09	04	02	29	00.2	7.3	50	-416	-0.332	0.996	142	102	1.5
Nice	12	14	17	34	39.4	4.7	-421	44	+0.009	0.043	207	315	1
OHP	12	14	17	34	35.6		-361	41	0.004	0.040			1

TABLE 1. (continued)

OBS.	1985 UT DATE					DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	Φ_1	Φ_2	Wgt
The following events are J3 occulting J2													
ESO	06	03	07	06	58.5	6.1	129	-691	0.260	-0.623	150	52	2
Low'l	06	10	10	13	29.0	5.7	122	-624	0.145	-0.313	149	55	2
TL	06	10	10	13	29.8		108	-566	0.139	-0.296			2
JW	06	10	10	13	28.9		125	-650	0.148	-0.320			2
ESO	06	10	10	13	29.5		111	-619	+0.146	-0.315			2
Catn	07	08	22	17	20.1	3.9	125	-594	-0.138	+0.452	145	66	1
Catn	07	16	01	14	27.8	3.1	145	-501	-0.182	0.573	144	68	1
Brzl	(07	16	01	14	25)		197	-645	-0.166	0.525			1.5
CI	07	16	01	14	25.5		183	-705	-0.160	0.509			1.5
Oak R	07	23	04	11	47.5	2.1	131	-577	-0.198	0.612	143	71	1.5
Brzl	(07	23	04	11	44.5)		170	-549	-0.200	0.617			1.5
KPNO	07	30	07	09	44.4	+1.0	156	-637	-0.206	0.630	143	74	1.5
Oak R	07	30	07	09	45.5		136	-561	-0.214	0.654			1.5
Brzl	(07	30	07	09	47.5)		114	-689	-0.199	0.609			1.5
Low'l	08	06	10	10	13.1	-0.4	58	-642	-0.216	0.650	142	77	2
Mt L	08	06	10	10	14.2		47	-561	-0.224	0.676			2
J/R	08	06	10	10	12.8		63	-619	-0.218	0.657			2
Rowe	08	06	10	10	17.1		27	-637	-0.215	0.649			2
WA	08	06	10	10	14.1		61	-669	-0.212	0.639			2
WA	08	13	13	13	24.0	-1.9	96	-575	-0.228	0.682	142	81	2
Perth	08	13	13	13	24.2		101	-609	-0.225	0.673			2
SAAO	08	27	19	37	14.8	-5.8	142	-548	-0.248	0.735	141	89	2
Catn	08	27	19	37	18.8		105	-585	-0.245	0.726			1
Perth	08	27	19	37	09.1		182	-458	-0.257	0.762			2
Catn	09	03	23	03	54.3	-7.6	111	-515	-0.268	0.792	141	93	1
CTIO	09	03	23	03	44.8		69	-614	-0.257	0.759	141	93	2
CTIO	09	05	03	24	51.1	+57.4	-386	225	+0.372	-0.968	201	215	1.5
CTIO	09	11	02	48	11.2	-11.4	101	-409	-0.297	+0.891	142	99	1.5
CTIO	09	12	00	08	13.0	+28.5	-456	154	-0.009	-0.063	187	191	2
SAAO	09	25	18	57	44.5	62.8	-247	-364	-0.315	+0.929	161	148	1.5
The following events are J3 eclipsing J4													
SAAO	09	05	21	25	42.2	4.1	826	-3	0.557	-1.582	232	333	1
Low'l	09	25	05	08	45.7	11.6	1370	-1065	0.123	-0.228	123	29	2
ESO	09	25	05	08	44.9		1377	-1064	0.122	-0.228			1.5

TABLE 1. (continued)

OBS.	1985 UT DATE	DT	DX	DZ	$D\alpha \cos\delta$	$D\delta$	Φ_1	Φ_2	Wgt
	The following events are J3 occulting J4								
SAAO	06 17 01 44 59.3	+9.5	1200	-1011	0.394	-1.011	124	29	2
Catn	06 17 01 44 37.3		1482	-940	0.385	-0.983			1.5
SAAO	08 05 23 27 04.7	-0.4	1379	-980	0.302	-0.951	120	30	2
	The following events are J4 eclipsing J1								
Low'l	08 29 03 22 30.0	+4.2	905	133	0.312	-0.860	168	71	2
Mt L	08 29 03 22 29.1		924	235	0.305	-0.847			2
ESO	08 29 03 22 29.8		908	177	0.308	-0.849			2
Rowe	10 02 09 08 27.6	-14.3	-546	(-770)	0.007	+0.075	183	194	1
Catn	10 02 19 36 00.8	+10.2	621	(-730)	0.053	-0.058	192	283	1
	The following events are J4 occulting J1								
SAAO	06 06 22 04 34.2	5.7	1231	-42	0.340	-0.857	170	53	1.5
M Kea	07 10 09 37 20.7	2.7	1464	141	0.118	-0.279	174	28	1.5
	(L Filter)								
M Kea	07 10 09 37 20.9		1456	133	0.120	-0.281			1
	(M Filter)								
M Kea	07 10 09 37 19.7		1486	182	0.114	-0.266			1.5
TL	07 10 09 37 21.8		1435	147	0.118	-0.278			1.5
JW	07 10 09 37 23.5		1391	233	0.108	-0.251			1.5
Sd Sp	07 27 17 08 19.0	+0.9	1215	-621	0.335	-0.996	189	313	2
	(L Filter)								
Perth	07 27 17 08 24.1		1122	-605	+0.333	-0.990			2
M Kea	12 24 01 18 39.8	-16.5	416	-160	-0.161	+0.431	167	97	1.5
	(L Filter)								
Low'l	12 24 01 18 42.0		383	-23	-0.174	0.462			1.5
M Kea	12 25 02 38 07.2	-4.7	1140	(-480)	-0.057	0.093	189	312	1
	(L Filter)								
	The following events are J4 eclipsing J2								
Rowe	09 14 12 29 39.9	+7.2	479	-353	-0.247	0.766	160	77	1.5
Perth	09 15 14 43 28.4	-15.8	255	-109	-0.132	0.419	183	189	1.5
Perth	11 05 12 54 29.6	+7.5	462	(-630)	+0.025	0.027	197	306	1

TABLE 1. (continued)

OBS.	1985 UT DATE	DT	DX	DZ	$D\alpha \cos \delta$	$D\delta$	Φ_1	Φ_2	Wgt
	The following events are J4 occulting J2								
Tokyo	06 06 17 55 57.6	4.4	729	−548	0.360	−0.921	166	42	1.5
Perth	07 26 12 34 16.6	1.2	595	(−470)	0.030	−0.065	164	52	1
	The following events are J4 eclipsing J3								
SAAO	08 31 01 59 15.3	5.4	56	−1036	0.454	−1.298	209	300	1
Oak R	09 30 23 29 25.4	12.6	754	21	0.179	−0.361	153	52	1.5
Barc	09 30 23 29 24.5		767	131	0.169	−0.333			1
CI	09 30 23 29 29.9		684	53	0.176	−0.352			2
	The following event is J4 occulting J3								
Catn	07 12 00 39 54.3	6.7	105	−1090	0.249	−0.649	209	301	2
Barc	07 12 00 39 58.5		53	−968	0.236	−0.610			1.5

all light curves considered here still appeared symmetrical and folding a light curve about its midpoint yielded a midtime in very close agreement with those in column 2.

The quantities under the heading DT in column 3 are the time offsets that must be added should one ever need to convert the midtimes referred to the light center in column 2 to ones defined by the minimum separation of the satellites' geometric centers. Although these corrections are derived from Lambert's law, Paper III showed that offsets calculated from other realistic scattering laws are indistinguishable.

The numbers in the next two columns, DX and DZ, are longitude and latitude corrections in km, measured in the plane of Jupiter's equator and perpendicular to it. The former are determined solely by the light curve midtimes, while the latter only by its amplitude. Because these corrections have been tabulated with respect to values predicted by Sampson's (1910, 1921) theory in the reductions of the 1973 and 1979 data, we have elected to retain the same reference format here. Had we used a more modern and precise theory, e.g., those of Lieske (1980) or Arlot (1982), the DX's and DZ's would have been much smaller, i.e., less than 150 km for characteristic cases. Although these two quantities as given are of limited interest, they are important as an aid for intercomparing results at this and other apparitions.

The next two columns contain the most useful contribution of this phase of the analysis. Listed first are the separations in right ascension, $D\alpha \cos \delta$ and then declination $D\delta$, between the two satellites at the times given in column 2. Presenting astrometric values in this form (referred to the mean equator and equinox of 1950) simplifies the process of joining these data with earlier positional measures to revise or extend theories of the motions of the satellites. These values are in the sense of the eclipsing (occulting) satellite minus the eclipsed (occulted) one; they are heliocentric separations for eclipses and geocentric for occultations. The 7th and 8th columns list orbital phase angles, (ϕ_1, ϕ_2) measured from superior geocentric conjunction for occultations, heliocentric conjunction for eclipses. One of three weights is assigned in the final column. These are quantitatively derived on the basis of the following three criteria: (1) the rms residuals of a fit of the model described earlier to the light curve; (2) the air mass at the light curve midtime; and (3) the aperture of the instrument used. This prescription was established in Papers II and III.

Any entry in parentheses in Table 1 has not been derived from the light curve but imposed upon it. There are several reasons for this procedure. In general we have preferred to reduce all the observations with the same programs and based on the same model as a way of maximizing the homogeneity of the results. However, some observations (e.g., certain ones presented by Arlot *et al.* 1989a,b) were printed in such a form as to make the given midtime more precise than one we could determine from our redigitizing of the published light curve. Another case in point arises for nearly central events that are annular or total so that the latitude correction, DZ, becomes poorly determined or even indeterminate. We have dealt with this problem here, as in past reductions, by computing a needed DZ from a revision to the principal constants of Sampson's theory as provided by all of the other events observed during this apparition (cf. Paper I). Nonetheless, such DZ's are less accurate so that, even though the midtime and consequently DX is well known, both $D\alpha \cos \delta$ and $D\delta$ are also less precise. All observations of this type have been accorded the lowest weight of 1.

TABLE 2. Mean parameters and standard errors of four events observed independently five or more times.

Event	No. of Obs.	Mean Midtime	DX	DZ	$D\alpha \cos\delta$	$D\delta$
1E2	7	09 14 03 22 44.04 ±0.73	45 ±7	-664 ±4	0.1100 ±0.0004	-0.2473 ±0.0011
1E2	6	09 21 06 03 21.88 ±0.70	156 ±8	-600 ±19	0.0752 ±0.0021	-0.1407 ±0.0049
3E2	5	08 06 10 20 42.70 ±0.64	52 ±8	-591 ±12	0.0554 ±0.0011	-0.1572 ±0.0032
3O2	5	08 06 10 10 14.26 ±0.76	51 ±7	-626 ±18	-0.2170 ±0.0020	0.6542 ±0.0062

The analysis of occultation light curves requires that the brightness ratio of the two satellites be known. This is not a trivial question because satellite brightnesses vary with orbital and solar phase angles, while Io's brightness depends on additional factors as well. Often observers were able to measure the needed ratios before and/or after the occultation. When this was not possible, extensive photometry carried out by Iain M. Coulson at SAAO and other measures at Oak Ridge supplied missing values at visual wavelengths. The raw data for all infrared occultations was kindly supplied by Jay Goguen now at JPL and the brightness ratios are taken from a paper of which he is first author (Goguen *et al.* 1988). The analysis in that paper has allowed us to correct the observed far-infrared light curves involving Io by removing the contribution due to discrete sources on its surface. The agreement between visual and IR light curves when both were observed argues that the presence of "hot spots" on Io has not led to an appreciable loss of accuracy.

To be really useful, results derived from mutual events must make up in quality what they necessarily fail to provide in quantity. There are four events in Table 1 for which five or more completely independent light curves were obtained. Table 2 lists certain mean parameters and the standard errors of these means for the sample case in which all observations were allowed equal weight. It seems clear that careful observations in good conditions can supply midtimes for which the accidental errors are less than 1 s and the positional separations good to about 0.01 arcsec. As part of another paper, we will investigate how well various theoretical representations can predict the observed satellite positions. With regard to the accuracy of current theories of the satellites' orbital motions, we note, following Arlot *et al.* (1989b), that the observed midtimes for seven observations of good quality differ from those given by two modern ephemerides by no more than about 15 s.

The two of us who analyzed the data and wrote this report would like to express special thanks to all of the Galilean Satellite Observers, the "GSO" listed earlier and to their colleagues for both the quality and quantity of their observations. Special thanks go to Iain Coulson, then at the South African Astronomical Observatory, both for the number of valuable light curves but also for extensive photometry yielding satellite brightness ratios needed for the analysis of occultations. We are also grateful for the extensive activities of our French colleagues and their associates whose published light curves we have analyzed and added to the results assembled in Table 1. The observations at Observatoire de Haute Provence (OHP) and at the European Southern Observatory (ESO) are presented and discussed by Arlot *et al.* (1989a,b). For other details concerning these observations and those made in Brazil (Brzl) and at Barcelona (Barc), consult papers by various authors in a special volume devoted to the subject: Ann. Phys. **12**, Suppl. No. 1 (1987). A paper by Froeschlé *et al.* (1988) is the source of light curves from the Observatoire de Nice (NICE).

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