MODELING PLUTO–CHARON MUTUAL EVENTS. II. CCD OBSERVATIONS WITH THE 60 in. TELESCOPE AT PALOMAR MOUNTAIN

B. J. BURATTI, R. S. DUNBAR, E. F. TEDESCO, J. GIBSON, R. L. MARCIALIS, F. WONG, AND S. BENNETT

Jet Propulsion Laboratory and Palomar Observatory California Institute of Technology 4800 Oak Grove Drive 183-501 Pasadena, California 91109

Electronic mail: buratti@jplpds.jpl.nasa.gov

A. DOBROVOLSKIS

University of California, Santa Cruz at NASA/Ames Research Center, Moffett Field, California 94035

Received 1994 June 24; revised 1995 April 3

ABSTRACT

We present observations of 15 Pluto–Charon mutual events which were obtained with the 60 in. telescope at Palomar Mountain Observatory. A CCD camera and Johnson *V* filter were used for the observations, except for one event that was observed with a Johnson *B* filter, and another event that was observed with a Gunn *R* filter. We observed two events in their entirety, and three pairs of complementary mutual occultation-transit events. © *1995 American Astronomical Society.*

1. INTRODUCTION

Since its discovery in 1930, Pluto has presented a challenge to observers because of its distance and small size. Ground-based observations of Pluto and its satellite Charon are particularly important because it is the only planetary system which has not been studied with a spacecraft. With the 1989 discovery by Voyager 2 that Neptune's satellite Triton—a body which is similar to Pluto in size and distance from the Sun—is a geologically diverse and active world, the importance of studying Pluto has been reemphasized. Like Triton, Pluto sustains a complex seasonal cycle (Stern & Trafton 1984) with concomitant growth and decay of polar caps and atmospheric volatiles (Trafton 1989). A recent suggestion (Stern 1991) that Pluto, Charon, and Triton are but three of perhaps thousands of similar bodies inhabiting the outer Solar System and the regions beyond further enhances Pluto–Charon's position of an object worthy of careful, detailed study. If this idea is correct, Pluto-type bodies would hold a large fraction of the mass of the Sun's planetary system, and their formation and current composition would have to be explained in any theory of the formation of solar systems.

Soon after the discovery of Pluto's satellite Charon (Christy & Harrington 1978), it was realized that the orbital plane of Charon would shortly be coaligned with Earth so that Pluto and Charon would exhibit a series of mutual eclipses (Andersson 1978). These events occur every 124 yr; the present series at perihelion occurs only every 248 yr, the orbital period of Pluto around the Sun. Accurate photometric measurements of these events provide an important tool to study the fundamental character of the Pluto–Charon system. Determination of the contact times and depth of the light curve for each event yields accurate estimates of the objects' sizes, geometric albedos, orbital elements, and combined density (Dunbar & Tedesco 1986, Paper I; Reinsch & Pakull 1987; Tholen *et al.* 1987a; Tholen & Buie 1990). The inversion of light curves formed by occultation of different surface areas on the Earth-facing hemispheres of the two bodies can produce an albedo map with far greater spatial resolution than is possible from with the *Hubble Space Telescope*, which can barely resolve Pluto's image (Binzel 1989; Buie & Tholen 1989; Albrecht *et al.* 1991; Burwitz *et al.* 1991; Buie *et al.* 1992; Young & Binzel 1993); from Earth Pluto's disk is unresolved. Because albedo and composition are correlated (Marcialis & Lebofsky 1991), these maps indicate the presence of regions with different surface compositions. Finally, albedo maps allow a deconvolution of the two factors responsible for the historic change in the amplitude of Pluto's rotational light curve: changing polar to equatorial viewing aspects, and seasonal deposition of volatiles (Marcialis 1988; Buie & Tholen 1989; Stern *et al.* 1988).

The first of this series of events was observed on 1985 January 16 by Tedesco and Buratti, on 1985 February 17 by Binzel, and on 1985 February 20 by Tholen (Binzel *et al.* 1985). These first events offered positive evidence of the existence of Charon. A number of groups have since been observing the events on a consistent basis (Tholen *et al.* 1987a; Binzel 1989; Blanco *et al.* 1989, 1991, 1994; Burwitz *et al.* 1991). This paper reports on the results of an observational program throughout the six year period of the events by a team of JPL astronomers using the 60 in. telescope on Palomar Mountain. Our goal was to produce a uniformly observed series of measurements with the same telescope, filters, and instruments (excepting an upgrade in the CCD chip). Data from 15 events were successfully obtained (Table 1). This paper reports on the observational results so that all researchers working in this area will have access to the data.

 0004-6256/95/110(3)/1405/15/$0.90

TABLE 1. Summary of events observed at Palomar Mountain Observatory. (60 inch telescope).

Number of Points	Event Time (UT)		Event Type S – Superior I – Interior	ZERO POINTS No. of Points	UT Start	UT End	AIRMASS START	END	OBSERVERS *
19	1985:	16 Jan	I	6	12.48	13.05	1.4	1.2	B,T
84		9 April	I	8	11.0	11.18	1.3	1.9	B,D
112	1986:	4 March	S	13	11.7	12.5	1.5	1.2	Do,G,T
230		20 March	I	19	11.0	11.3	1.3	1.3	Do,G, N
119		5 April	S	14	6.1	6.6	1.9	1.3	B,D
101		8 April	I	19	10.18	10.78	1.3	1.8	G
49		8 June	S	6	7.7	8.3	1.2	1.5	B,D,G
63		11 June	I	17	7.0	8.0	1.3	3.3	B,D
61		27 June	S	10	6.7	7.1	1.2	1.9	B,T
82	1987:	25 July	S	23	6.3	7.3	1.4	3.5	G
74	1988:	14 March	S	16	9.16	10.0	2.5	1.3	G
123		17 March	I	12	8.9	9.3	1.4	1.4	G
127		17 May	S	11	6.4	6.8	1.7	1.2	G
164		5 June	S	7	5.13	5.26	1.2	4.1	G
49	1990:	19 June	I	10	6.52	8.29	1.3	3.7	B,M

* KEY: B – B. J. Buratti; D – R. S. Dunbar; Do – A. Dobrovolskis; G – J. Gibson; M – R. Marcialis; N - R. Nelson; T – E. Tedesco

2. OBSERVATIONS AND DATA ANALYSIS

All observations were obtained with a CCD camera mounted at the Cassegrain focus of the 60 in. reflecting telescope on Palomar Mountain. During 1985 to 1987, a TI 320 ×520 CCD silicon array detector was used; in 1988 the camera was upgraded with a TI 365 800×800 array detector. Because a large field of view was required to assure that at least two appropriate comparison stars appeared on the image for each event, the field of view of our images was increased by means of reimaging optics to approximately 6 by 10 arcmin (8.25 arcmin square after the CCD upgrade). To assure the maximum ability for comparison with other observers, all events were observed in the Johnson *V* filter, except for 1985 April 9—a cirrusy moonlit night—which was observed in the Gunn *R* filter, and the first event, which was observed in the *B* filter. A few exposures in the *B* and *R* filters were obtained to insure that the colors of the comparison stars were similar to Pluto. Exposure times ranged from 8 to 50 s, depending on the airmass and photometric conditions, with images separated by approximately two minutes. The maximum DN level for Pluto–Charon was typically 5–10 times that of the sky background. The star field was sparse throughout the six years of the events' duration, so that confusion of Pluto–Charon or the comparison stars with background stars was never a problem in data analysis. The angular distance between Pluto and the comparison stars ranges from 0.5 to 2 arcmin. Seeing was 2–4 arcsec; for most of the 1986 March 20 and 1990 June 6 events it was ~1 arcsec. For all events, motion was apparent during the course of the night's observations.

Each CCD frame represents a single point in our light curves. The images were processed in the standard fashion: unshuttered (bias) exposures were subtracted from the images, which were then corrected for field variations in sensitivity. The bias was constant to ~1% for the duration of all the nights we observed. The flatfield frames were produced at the beginning and end of each night by flooding the top of the telescope dome with an incandescent light and exposing the CCD camera until it reached approximately the center of its linear range; 10–15 such frames were averaged for the flatfield image used in the reductions. This technique effectively removed the flatfield pattern and blemishes on the image. Relative photometric measurements of Pluto with respect to two on-image stars were then computed. The brightness of Pluto/Charon and the two comparison stars, which were chosen to have the same approximate brightness and color as the planet, were computed by summing all the DNs within a square aperture of ~5 arcsec on each side. The background for each object was computed by placing four boxes also ~5 arcsec outside each corner of the aperture, computing the average background per pixel, and subtracting the appropriate amount from Pluto–Charon and the two comparison stars. Although the software written to reduce the data was automated, we displayed each image on a graphics screen with the objects' apertures and sky boxes explicitly drawn on the screen to confirm that no field stars,

TABLE 2. CCD photometry of Pluto/Charon.

U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ
			11.5994	0.003	0.018	12.5856	0.018	0.009	10.4354	0.100	0.006
1985 January 16	*Inf.*	*B*	11.6161	0.022	0.015	12.6403	0.012	0.015	10.4688	0.099	0.006
			11.6328	0.020	0.019	12.6536	0.020	0.015	10.5021	0.090	0.006
11.0228	0.030	0.003	11.6494	0.021	0.016	12.6681	-0.010	0.017	10.5354	0.094	0.006
11.2084	0.043	0.004	11.6661	0.022	0.017	12.6828	-0.007	0.017	10.5688	0.096	0.007
11.3833	0.033	0.009	11.6953	0.018	0.014	12.6994	0.015	0.014	10.6021	0.075	0.006
11.6667	0.001	0.003	11.7161	0.018	0.013	12.7161	0.022	0.017	10.6354	0.083	0.008
12.1292	0.002	0.003	11.7328	0.001	0.007				10.6688	0.092	0.009
12.2542	0.003	0.003	11.7494	0.018	0.008	1986 March 04	*Sup.*	*V*	10.7021	0.055	0.009
12.3694	-0.003	0.004	11.7661	0.028	0.008				10.7354	0.083	0.008
12.4833	0.007	0.003	11.7828	0.011	0.009	9.0215	0.086	0.007	10.7688	0.066	0.008
12.5958	0.001	0.004	11.7994	0.013	0.007	9.0854	0.091	0.009	10.8024	0.063	0.005
12.7208	0.000	0.004	11.8161	0.011	0.007	9.1188	0.102	0.010	10.8354	0.059	0.005
12.8333	-0.008	0.006	11.8328	0.018	0.009	9.1521	0.106	0.009	10.9688	0.050	0.008
12.9458	0.004	0.007	11.8494	0.018	0.013	9.1854	0.107	0.008	11.0021	0.037	0.007
13.0556	-0.004	0.007	11.8661	0.017	0.010	9.2188	0.123	0.007	11.0354	0.030	0.007
13.1567	0.000	0.004	11.8828	0.011	0.011	9.2521	0.118	0.006	11.0688	0.044	0.005
13.2292	-0.007	0.005	11.8994	0.039	0.011	9.2854	0.114	0.005	11.1021	0.031	0.007
13.3931	-0.002	0.004	11.9161	0.007	0.008	9.3188	0.109	0.005	11.1354	0.028	0.007
13.5042	-0.001	0.003	11.9328	0.009	0.005	9.3521	0.119	0.005	11.1693	0.066	0.007
13.6236	0.002	0.010	11.9494	0.008	0.005	9.3854	0.109	0.006	11.2021	0.013	0.006
13.7361	0.002	0.009	11.9661	0.016	0.005	9.4188	0.129	0.005	11.2354	0.061	0.006
			12.0036	0.018	0.005	9.4521	0.120	0.007	11.2743	0.027	0.006
1985 April 09	*Inf.*	*R*	12.0383	0.025	0.006	9.4854	0.131	0.008	11.3021	0.011	0.008
			12.0578	0.025	0.008	9.5188	0.121	0.009	11.3354	-0.016	0.008
10.9994	0.001	0.007	12.0772	0.018	0.012	9.5521	0.121	0.010	11.3688	0.000	0.008
11.0425	-0.001	0.009	12.0994	0.024	0.011	9.5882	0.147	0.010	11.4021	0.027	0.008
11.0689	0.000	0.015	12.1217	0.011	0.011	9.6188	0.131	0.008	11.4354	0.045	0.007
11.0828	-0.001	0.013	12.1356	0.009	0.013	9.6576	0.117	0.007	11.4771	0.029	0.005
11.1161	-0.011	0.013	12.1536	0.020	0.010	9.6799	0.144	0.009	11.5063	0.023	0.006
11.1328	-0.016	0.016	12.1717	0.010	0.008	9.7354	0.112	0.008	11.5354	0.024	0.006
11.1494	0.010	0.015	12.1869	0.002	0.009	9.7688	0.125	0.010	11.5688	-0.004	0.006
11.1661	0.017	0.014	12.2008	0.001	0.010	9.8021	0.119	0.010	11.6024	-0.002	0.006
11.2203	0.005	0.012	12.2161	0.018	0.008	9.8354	0.129	0.011	11.6354	-0.002	0.006
11.2994	0.011	0.016	12.2328	0.007	0.011	9.8688	0.135	0.010	11.6688	0.014	0.008
11.3161	0.010	0.017	12.2969	0.014	0.012	9.9021	0.126	0.010	11.7021	0.000	0.009
11.3369	-0.018	0.020	12.3106	0.012	0.013	9.9354	0.121	0.008	11.7354	0.003	0.009
11.3522	-0.006	0.019	12.3356	0.004	0.014	9.9690	0.130	0.009	11.9191	0.005	0.008
11.3675	0.000	0.019	12.3508	0.006	0.015	10.0021	0.124	0.010	11.8021	0.000	0.010
11.3842	0.004	0.015	12.3508	0.011	0.013	10.0410	0.133	0.008	11.8354	0.008	0.006
11.3994	0.000	0.011	12.3661	0.005	0.013	10.0688	0.126	0.007	11.8688	-0.011	0.007
11.4161	0.016	0.011	12.3824	0.012	0.012	10.1021	0.123	0.007	11.9021	-0.004	0.009
11.4328	0.012	0.010	12.3994	0.012	0.010	10.1354	0.126	0.006	11.9354	-0.009	0.010
11.4494	0.016	0.010	12.4161	0.017	0.012	10.1688	0.134	0.005	11.9688	-0.013	0.008
11.4661	0.002	0.012	12.4508	0.011	0.014	10.2021	0.116	0.006	12.0021	0.006	0.009
11.4828	0.024	0.013	12.4661	0.026	0.017	10.2354	0.123	0.007	12.0354	-0.005	0.007
11.4994	0.025	0.010	12.4828	0.011	0.016	10.2701	0.113	0.007	12.0715	0.012	0.005
11.5356	0.030	0.014	12.4994	0.020	0.016	10.3021	0.122	0.007	12.1049	0.002	0.004
11.5494	0.019	0.014	12.5286	0.015	0.013	10.3354	0.121	0.006	12.1354	0.006	0.007
11.5689	0.013	0.016	12.5494	0.007	0.009	10.3688	0.095	0.005	12.1688	0.014	0.007
11.5828	0.003	0.014	12.5678	0.023	0.007	10.4021	0.106	0.004	12.2049	-0.007	0.007

TABLE 2. (continued)

U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ
12.2354	0.027	0.008	9.0000	0.264	0.013	9.8500	0.161	0.007	10.7167	0.015	0.008
12.2688	0.006	0.008	9.0167	0.238	0.011	9.8667	0.162	0.008	10.7333	0.035	0.008
12.3021	0.008	0.008	9.0333	0.279	0.012	9.8833	0.174	0.010	10.7500	0.013	0.008
12.3354	0.019	0.008	9.0500	0.249	0.012	9.9000	0.161	0.010	10.7669	0.021	0.009
12.3688	0.001	0.008	9.0667	0.253	0.011	9.9167	0.163	0.010	10.7833	0.023	0.011
12.4021	0.019	0.007	9.0833	0.255	0.012	9.9333	0.165	0.010	10.8000	−0.013	0.010
12.4354	0.016	0.009	9.1000	0.244	0.012	9.9500	0.151	0.009	10.8167	0.026	0.011
12.4688	0.003	0.006	9.1167	0.234	0.012	9.9667	0.126	0.008	10.8333	0.005	0.011
12.5021	−0.006	0.006	9.1333	0.253	0.012	9.9833	0.148	0.009	10.8514	−0.021	0.012
12.5354	−0.002	0.006	9.1500	0.260	0.009	10.0000	0.145	0.011	10.8667	0.005	0.012
12.5688	−0.021	0.006	9.1639	0.259	0.008	10.0167	0.133	0.011	10.8833	0.002	0.014
12.6026	0.001	0.005	9.1833	0.247	0.008	10.0333	0.128	0.011	10.9000	−0.012	0.013
12.6382	−0.007	0.005	9.2000	0.280	0.007	10.0500	0.124	0.011	10.9167	−0.017	0.015
12.6688	0.029	0.005	9.2167	0.290	0.007	10.0667	0.136	0.009	10.9333	−0.009	0.013
12.7076	0.014	0.006	9.2333	0.260	0.007	10.0833	0.141	0.008	10.9500	−0.007	0.011
12.7354	0.031	0.005	9.2500	0.271	0.007	10.1000	0.124	0.008	10.9667	−0.014	0.011
12.7688	0.013	0.006	9.2667	0.245	0.007	10.1167	0.119	0.007	10.9833	−0.011	0.011
			9.2833	0.251	0.012	10.1333	0.111	0.007	11.0000	−0.018	0.009
1986 March 20	*Inf.*	V	9.3000	0.258	0.012	10.1500	0.116	0.007	11.0167	0.019	0.009
			9.3167	0.208	0.012	10.1667	0.105	0.008	11.0333	−0.010	0.009
8.4694	0.188	0.005	9.3333	0.243	0.011	10.1833	0.103	0.008	11.0500	0.000	0.007
8.4861	0.192	0.007	9.3500	0.231	0.012	10.2000	0.113	0.009	11.0667	0.000	0.008
8.5000	0.182	0.012	9.3667	0.272	0.011	10.2167	0.100	0.011	11.0833	−0.004	0.010
8.5167	0.194	0.012	9.3833	0.251	0.011	10.2333	0.101	0.012	11.1000	0.020	0.010
8.5333	0.196	0.013	9.4000	0.235	0.012	10.2500	0.108	0.011	11.1167	0.009	0.010
8.5500	0.219	0.011	9.4167	0.255	0.012	10.2667	0.095	0.011	11.1333	−0.014	0.010
8.5667	0.207	0.015	9.4333	0.246	0.011	10.3000	0.092	0.010	11.1500	0.001	0.009
8.5833	0.207	0.013	9.4500	0.228	0.009	10.3167	0.086	0.008	11.1667	−0.004	0.007
8.6000	0.216	0.014	9.4667	0.230	0.012	10.3333	0.080	0.007	11.1833	−0.004	0.007
8.6167	0.191	0.013	9.4833	0.221	0.014	10.3500	0.108	0.007	11.2000	0.007	0.007
8.6333	0.221	0.015	9.5000	0.211	0.016	10.3667	0.089	0.008	11.2167	−0.019	0.007
8.6500	0.224	0.011	9.5167	0.260	0.016	10.3833	0.077	0.008	11.2333	0.016	0.007
8.6667	0.215	0.011	9.5333	0.232	0.015	10.4000	0.081	0.008	11.2500	−0.007	0.007
8.6833	0.218	0.011	9.5500	0.229	0.013	10.4167	0.088	0.008	11.2667	0.006	0.009
8.7000	0.229	0.011	9.5667	0.228	0.010	10.4333	0.072	0.008	11.2833	0.008	0.014
8.7167	0.245	0.009	9.5833	0.238	0.008	10.4500	0.071	0.007	11.3000	0.003	0.016
8.7500	0.239	0.010	9.6000	0.221	0.008	10.4681	0.056	0.007	11.3167	0.017	0.016
8.7667	0.243	0.009	9.6167	0.233	0.008	10.4833	0.082	0.008	11.3333	0.009	0.017
8.7833	0.237	0.009	9.6333	0.207	0.007	10.5000	0.063	0.010	11.3500	−0.014	0.015
8.8000	0.254	0.011	9.6500	0.208	0.007	10.5167	0.070	0.010	11.3667	−0.014	0.010
8.8167	0.261	0.011	9.6667	0.215	0.009	10.5333	0.072	0.011	11.3833	−0.001	0.008
8.8333	0.248	0.011	9.6833	0.190	0.009	10.5500	0.061	0.011	11.4000	0.006	0.009
8.8500	0.252	0.010	9.7000	0.225	0.010	10.5667	0.026	0.010	11.4167	−0.022	0.009
8.8667	0.245	0.011	9.7167	0.197	0.011	10.5833	0.038	0.011	11.4333	0.024	0.009
8.8833	0.264	0.008	9.7333	0.198	0.011	10.6000	0.044	0.012	11.4500	−0.016	0.009
8.9000	0.239	0.008	9.7500	0.186	0.011	10.6167	0.051	0.011	11.4667	−0.005	0.011
8.9167	0.276	0.010	9.7667	0.186	0.011	10.6333	0.040	0.011	11.5000	0.001	0.009
8.9333	0.247	0.012	9.7833	0.192	0.010	10.6500	0.039	0.011	11.5167	0.021	0.011
8.9500	0.260	0.012	9.8000	0.197	0.008	10.6667	0.035	0.007	11.5333	−0.006	0.011
8.9667	0.276	0.012	9.8167	0.193	0.008	10.6833	0.032	0.007	11.5500	−0.020	0.011
8.9833	0.267	0.015	9.8333	0.130	0.007	10.7000	0.043	0.008	11.5667	−0.019	0.010

TABLE 2. (continued)

U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ
11.5833	0.000	0.010	6.0708	0.003	0.011	7.8764	0.102	0.007	10.3706	0.007	0.015
11.6000	-0.006	0.010	6.1042	0.003	0.012	7.9014	0.118	0.007	10.4181	-0.002	0.015
11.6167	-0.018	0.010	6.1354	0.031	0.012	7.9347	0.146	0.006	10.6575	0.052	0.015
11.6333	-0.008	0.010	6.2021	0.007	0.011	7.9681	0.130	0.008	10.7014	0.066	0.010
11.6500	-0.012	0.009	6.2438	0.007	0.008	8.0014	0.125	0.009	10.7514	0.054	0.009
11.6667	0.007	0.010	6.2688	0.009	0.008	8.0353	0.121	0.013	10.8097	0.055	0.012
11.6833	-0.012	0.009	6.3021	-0.003	0.010	8.0681	0.143	0.013	10.8664	0.060	0.008
11.7000	-0.022	0.010	6.3354	0.007	0.009	8.1031	0.154	0.017	10.9014	0.033	0.009
11.7167	-0.001	0.011	6.3688	0.010	0.011	8.1347	0.134	0.015	10.9458	0.045	0.009
11.7333	-0.008	0.011	6.4021	-0.041	0.012	8.1681	0.148	0.017	11.0042	0.063	0.008
11.7500	-0.006	0.010	6.4354	-0.006	0.011	8.2014	0.134	0.013	11.0542	0.067	0.005
11.7667	-0.001	0.011	6.4713	0.006	0.007	8.2389	0.132	0.013	11.1097	0.074	0.007
11.7833	0.015	0.010	6.5021	0.006	0.008	8.2681	0.159	0.010	11.1681	0.073	0.014
11.8000	0.013	0.010	6.5354	-0.030	0.005	8.3014	0.147	0.008	11.2264	0.047	0.013
11.8167	0.005	0.010	6.5693	-0.011	0.004	8.3347	0.144	0.007			
11.8333	-0.003	0.010	6.6021	0.007	0.006	8.3681	0.132	0.007	1986 April 08 *Inf.* V		
11.8500	-0.015	0.009	6.6354	0.014	0.006	8.4036	0.174	0.008			
11.8667	0.009	0.008	6.6688	0.010	0.007	8.4347	0.165	0.008	9.3167	0.040	0.030
11.8833	0.030	0.007	6.7021	0.026	0.011	8.4681	0.137	0.008	9.3500	0.002	0.034
11.9000	0.002	0.007	6.7365	0.002	0.012	8.5019	0.145	0.006	9.3833	-0.004	0.036
11.9167	0.002	0.007	6.7688	0.002	0.012	8.5347	0.102	0.006	9.4167	-0.035	0.030
11.9333	-0.007	0.011	6.8021	0.053	0.012	8.5681	0.116	0.006	9.4500	0.005	0.022
11.9489	0.006	0.011	6.8354	0.032	0.012	8.6014	0.126	0.010	9.4833	-0.029	0.035
11.9667	0.042	0.012	6.8688	0.012	0.010	8.6347	0.138	0.009	9.5172	0.011	0.048
11.9833	0.006	0.013	6.9021	0.002	0.009	8.6681	0.154	0.015	9.5500	-0.013	0.062
12.0000	0.016	0.013	6.9354	0.020	0.009	8.7056	0.109	0.015	9.5833	0.027	0.061
12.0167	0.034	0.010	6.9688	0.039	0.009	9.1847	0.123	0.013	9.6167	-0.017	0.062
12.0333	0.006	0.010	7.0021	0.043	0.008	9.2178	0.114	0.011	9.6500	0.002	0.053
12.0500	0.021	0.011	7.0354	0.059	0.009	9.2511	0.100	0.015	9.6833	-0.007	0.040
12.0667	0.004	0.009	7.0688	0.049	0.009	9.2678	0.083	0.011	9.7167	0.021	0.035
12.0833	-0.005	0.009	7.1021	0.045	0.007	9.3414	0.101	0.014	9.7500	-0.007	0.036
12.1000	-0.006	0.010	7.1354	0.074	0.007	9.4011	0.089	0.014	9.7833	-0.007	0.033
12.1167	-0.016	0.010	7.1729	0.072	0.006	9.5011	0.076	0.014	9.8167	0.002	0.024
12.1333	0.008	0.010	7.2021	0.067	0.004	9.5178	0.098	0.011	9.8500	0.008	0.024
12.1500	0.012	0.010	7.2354	0.055	0.005	9.5344	0.079	0.016	9.8833	-0.029	0.024
12.1681	0.009	0.010	7.2771	0.070	0.007	9.5511	0.102	0.016	9.9167	0.011	0.024
12.1833	-0.001	0.008	7.3181	0.083	0.007	9.5844	0.031	0.016	9.9500	-0.004	0.029
12.2000	-0.024	0.008	7.3556	0.089	0.006	9.6011	0.073	0.016	9.9833	-0.013	0.028
12.2167	-0.003	0.008	7.4014	0.120	0.006	9.6178	0.093	0.015	10.0167	-0.007	0.028
12.2333	0.004	0.009	7.4347	0.113	0.007	9.6344	0.073	0.013	10.0511	0.014	0.024
12.2500	0.002	0.009	7.4681	0.107	0.005	9.6678	0.066	0.014	10.0833	-0.001	0.021
12.2667	-0.014	0.009	7.5014	0.097	0.009	9.7178	0.049	0.015	10.1167	-0.052	0.020
12.2833	-0.005	0.011	7.5681	0.129	0.010	9.7678	0.063	0.016	10.1500	0.021	0.018
12.3000	0.011	0.011	7.6011	0.126	0.011	9.8344	0.054	0.018	10.1833	-0.026	0.019
12.3167	0.000	0.008	7.6344	0.099	0.009	9.8678	0.083	0.014	10.2167	0.027	0.014
12.3333	0.020	0.011	7.6678	0.115	0.009	9.9178	0.049	0.009	10.2500	-0.032	0.015
			7.7011	0.143	0.007	9.9678	0.083	0.008	10.2833	-0.007	0.012
1986 April 05 *Sup.* V			7.7344	0.133	0.007	10.0011	0.079	0.008	10.3167	0.002	0.011
			7.7678	0.137	0.008	10.0511	0.073	0.007	10.3500	0.014	0.006
6.0042	0.023	0.006	7.8011	0.148	0.009	10.2683	0.047	0.012	10.3872	-0.001	0.010
6.0417	0.013	0.010	7.8344	0.113	0.008	10.3178	0.033	0.015	10.4167	-0.020	0.010

TABLE 2. (continued)

U.T.	Δm	σ
10.4511	0.011	0.014
10.4833	0.027	0.014
10.5167	0.002	0.016
10.5500	0.033	0.018
10.5833	–0.001	0.023
10.6167	0.027	0.023
10.6500	–0.007	0.026
10.6833	–0.023	0.026
10.7172	0.011	0.023
10.7500	0.011	0.019
10.7833	–0.004	0.014
10.8119	–0.032	0.012
10.8500	0.021	0.011
10.8833	–0.017	0.011
10.9172	–0.004	0.011
10.9500	–0.035	0.016
10.9833	–0.010	0.014
11.0167	–0.019	0.020
11.0500	–0.019	0.015
11.0833	–0.019	0.020
11.1167	–0.010	0.014
11.1500	–0.017	0.016
11.1833	–0.012	0.011
11.2167	0.017	0.012
11.2500	0.002	0.010
11.2917	–0.010	0.015
11.3250	0.002	0.014
11.3500	–0.020	0.014
11.3833	0.005	0.014
11.4167	0.033	0.011
11.4500	0.040	0.009
11.4833	0.014	0.008
11.5167	0.014	0.012
11.5500	0.014	0.014
11.5833	0.033	0.016
11.6167	0.036	0.018
11.6500	0.043	0.019
11.6833	0.046	0.021
11.7167	0.027	0.022
11.7500	0.079	0.021
11.7833	0.033	0.021
11.8167	0.014	0.025
11.8500	0.085	0.020
11.8833	0.049	0.020
11.9167	0.069	0.020
11.9500	0.072	0.016
11.9833	0.075	0.016
12.0167	0.092	0.020
12.0500	0.092	0.017
12.0833	0.109	0.017
12.1167	0.119	0.016

U.T.	Δm	σ
12.1500	0.102	0.014
12.1833	0.133	0.012
12.2167	0.105	0.015
12.2500	0.136	0.017
12.2833	0.143	0.020
12.3167	0.133	0.020
12.3500	0.092	0.019
12.3833	0.143	0.021
12.4167	0.150	0.022
12.4500	0.186	0.024
12.4833	0.129	0.026
12.5167	0.143	0.026
12.5500	0.125	0.021
12.5833	0.105	0.021
12.6500	0.209	0.020
12.6833	0.194	0.015
1986 June 08 *Sup.* *V*		
4.4257	0.000	0.006
4.4521	–0.007	0.007
4.4715	0.040	0.009
4.4854	0.015	0.008
4.5076	0.046	0.006
4.5243	0.024	0.006
4.5382	0.035	0.006
4.5965	0.019	0.007
4.6188	0.031	0.006
4.6479	0.060	0.006
4.6688	0.074	0.005
4.6854	0.050	0.006
4.7063	0.032	0.004
4.7438	0.038	0.003
4.7688	0.054	0.006
4.7854	0.042	0.006
4.8076	0.059	0.007
4.8396	0.081	0.007
4.8521	0.061	0.008
4.9058	0.045	0.006
4.9350	0.071	0.007
4.9767	0.077	0.009
5.0392	0.076	0.009
5.0604	0.064	0.009
5.0771	0.079	0.012
5.0938	0.065	0.014
5.1104	0.091	0.012
5.2729	0.088	0.014
5.3201	0.105	0.004
5.3354	0.097	0.004
5.3771	0.108	0.003
5.4021	0.098	0.003

U.T.	Δm	σ
5.4188	0.107	0.003
5.4549	0.094	0.003
5.4715	0.086	0.003
5.4882	0.105	0.004
5.5021	0.101	0.005
7.8868	0.000	0.007
7.9354	–0.021	0.008
7.9521	–0.001	0.011
7.9896	0.005	0.009
8.0076	0.013	0.011
8.0215	0.002	0.008
8.0396	0.004	0.011
1986 June 11 *Inf.* *V*		
7.2753	0.009	0.043
7.3003	0.015	0.043
7.3669	0.027	0.042
7.4669	–0.003	0.047
7.5003	0.090	0.048
7.5336	–0.015	0.045
7.5681	0.046	0.039
7.6014	0.064	0.037
7.6347	0.059	0.036
7.6681	–0.010	0.041
7.7097	–0.033	0.042
7.7542	0.009	0.042
7.8681	–0.006	0.044
7.9017	0.035	0.038
7.9350	0.006	0.039
7.9711	–0.040	0.039
8.0044	0.020	0.041
8.0350	–0.014	0.041
8.0683	0.017	0.042
8.1017	0.055	0.042
8.1350	0.024	0.042
8.1725	0.010	0.037
8.2044	–0.020	0.036
8.2350	0.000	0.036
8.2683	0.017	0.033
8.3017	–0.042	0.041
8.3350	–0.002	0.035
8.3683	0.038	0.036
8.4058	0.035	0.037
8.4392	0.141	0.052
8.4767	0.067	0.039
8.5183	0.044	0.039
8.5517	0.091	0.038
8.5933	0.074	0.038
8.6350	0.070	0.038
8.6704	0.071	0.039

U.T.	Δm	σ
8.7024	0.090	0.039
8.7357	0.069	0.039
8.7690	0.088	0.039
8.8065	0.112	0.040
8.8454	0.000	0.051
8.8871	0.069	0.047
8.9204	0.059	0.046
8.9704	0.049	0.047
9.0121	0.136	0.038
9.0538	0.130	0.038
9.0871	0.028	0.053
9.1704	0.166	0.046
9.2121	0.083	0.042
9.2538	0.042	0.050
9.2954	0.112	0.041
9.3371	0.151	0.041
9.3704	0.124	0.043
9.4038	0.150	0.042
9.4454	0.183	0.040
9.4871	0.081	0.051
9.5204	0.180	0.036
9.5621	0.149	0.035
9.6038	0.190	0.036
9.6454	0.163	0.037
9.6871	0.313	0.120
9.7399	0.180	0.042
9.8038	0.185	0.043
1986 June 27 *Sup.* *V*		
6.7194	0.020	0.010
6.7528	–0.005	0.020
6.7861	0.001	0.028
6.8194	–0.007	0.023
6.8528	0.004	0.005
6.8861	0.000	0.007
6.9194	0.022	0.008
6.9528	–0.020	0.009
6.9861	–0.040	0.007
7.0194	0.023	0.008
7.0528	0.042	0.008
7.0903	0.014	0.025
7.1250	0.022	0.017
7.1583	–0.033	0.023
7.2111	0.030	0.021
7.2389	–0.001	0.005
7.2764	–0.005	0.005
7.3069	0.004	0.005
7.3361	0.033	0.017
7.3694	–0.002	0.006
7.4028	0.001	0.010

TABLE 2. (continued)

U.T.	Δm	σ
7.4361	0.049	0.020
7.4694	0.018	0.012
7.5028	0.028	0.005
7.5361	−0.016	0.014
7.5694	0.007	0.010
7.6028	0.021	0.019
7.6361	0.011	0.020
7.6694	0.021	0.005
7.7028	0.012	0.010
7.7378	0.017	0.005
7.7861	0.038	0.005
7.8231	0.016	0.006
7.8694	0.012	0.005
7.9139	0.015	0.005
7.9569	0.001	0.011
7.9819	0.052	0.008
8.0306	0.008	0.007
8.0694	0.045	0.014
8.1194	0.072	0.013
8.1528	0.040	0.018
8.2069	0.067	0.010
8.2444	0.048	0.008
8.2861	0.047	0.005
8.3306	0.068	0.011
8.3694	0.106	0.015
8.5069	0.068	0.008
8.5528	0.075	0.027
1987 July 25	*Inf.*	V
4.2947	0.495	0.013
4.3714	0.499	0.015
4.4253	0.490	0.018
4.4636	0.510	0.016
4.4919	0.509	0.015
4.5253	0.501	0.013
4.5592	0.482	0.014
4.5919	0.476	0.014
4.6253	0.492	0.012
4.6586	0.493	0.012
4.6919	0.464	0.017
4.7253	0.455	0.017
4.7586	0.437	0.016
4.7919	0.443	0.016
4.8253	0.424	0.016
4.8586	0.428	0.013
4.8919	0.409	0.013
4.9253	0.393	0.013
4.9586	0.376	0.014
4.9919	0.371	0.014
5.0253	0.357	0.014
5.0586	0.335	0.014
5.0919	0.322	0.015
5.1253	0.327	0.015
5.1586	0.320	0.016
5.1917	0.293	0.015
5.2267	0.294	0.013
5.2586	0.275	0.013
5.2919	0.266	0.012
5.3253	0.266	0.012
5.3586	0.265	0.014
5.3917	0.246	0.016
5.4253	0.229	0.016
5.4586	0.217	0.017
5.4919	0.236	0.018
5.5253	0.219	0.017
5.5586	0.196	0.017
5.5919	0.214	0.017
5.6253	0.184	0.015
5.6586	0.201	0.015
5.6919	0.147	0.014
5.7253	0.168	0.015
5.7586	0.125	0.015
5.7917	0.121	0.015
5.8253	0.119	0.015
5.8586	0.109	0.013
5.8922	0.102	0.013
5.9253	0.082	0.017
5.9669	0.059	0.017
5.9933	0.061	0.018
6.0267	0.054	0.027
6.0558	0.013	0.025
6.0892	0.030	0.021
6.1225	0.043	0.020
6.1558	0.015	0.021
6.1892	0.060	0.020
6.2225	−0.001	0.020
6.2556	−0.018	0.020
6.2894	0.052	0.029
6.3167	0.070	0.026
6.3558	−0.040	0.018
6.3892	0.033	0.019
6.4225	0.065	0.017
6.4619	0.048	0.010
6.4900	−0.072	0.020
6.5236	0.007	0.024
6.5558	0.028	0.039
6.5892	−0.011	0.043
6.6228	−0.011	0.048
6.6558	−0.029	0.049
6.6894	0.012	0.046
6.7228	0.054	0.030
6.7558	−0.024	0.046
6.7892	−0.025	0.053
6.8225	−0.011	0.042
6.8561	0.010	0.057
6.8894	−0.022	0.068
6.9228	−0.002	0.049
6.9561	−0.037	0.055
6.9892	0.086	0.072
7.0228	−0.060	0.056
7.0561	−0.055	0.072
1988 March 14	*Sup.*	V
7.2122	0.153	0.011
7.2469	0.143	0.014
7.2767	0.154	0.014
7.3100	0.134	0.013
7.3450	0.121	0.013
7.3747	0.121	0.012
7.4083	0.145	0.015
7.4414	0.180	0.016
7.4747	0.151	0.017
7.5081	0.179	0.019
7.5417	0.162	0.017
7.5750	0.153	0.016
7.6086	0.163	0.019
7.6444	0.167	0.020
7.6989	0.150	0.018
7.7414	0.134	0.016
7.7747	0.150	0.016
7.8083	0.144	0.014
7.8414	0.127	0.012
7.8750	0.140	0.012
7.9081	0.136	0.015
7.9417	0.129	0.017
7.9747	0.123	0.015
8.0081	0.103	0.015
8.0414	0.121	0.015
8.0747	0.106	0.012
8.1081	0.119	0.009
8.1414	0.112	0.013
8.1747	0.089	0.013
8.2081	0.090	0.012
8.2414	0.095	0.015
8.2747	0.097	0.013
8.3081	0.069	0.009
8.3414	0.058	0.013
8.3747	0.096	0.016
8.4081	0.069	0.015
8.4417	0.072	0.018
8.4747	0.068	0.017
8.5081	0.051	0.013
8.5417	0.072	0.011
8.5747	0.061	0.011
8.6083	0.040	0.010
8.6422	0.056	0.014
8.6747	0.055	0.021
8.7078	0.036	0.023
8.7411	0.020	0.025
8.7747	0.010	0.027
8.8081	0.040	0.025
8.8414	0.037	0.020
8.8747	0.061	0.021
8.9081	0.007	0.020
8.9411	0.037	0.014
8.9742	0.040	0.014
9.0083	0.028	0.014
9.0422	−0.001	0.016
9.0747	0.017	0.017
9.1086	0.050	0.022
9.1414	−0.004	0.030
9.1750	−0.020	0.029
9.2083	−0.004	0.027
9.2417	0.008	0.026
9.2750	0.024	0.025
9.3081	0.029	0.024
9.3417	0.001	0.028
9.3747	−0.018	0.029
9.4083	−0.008	0.028
9.4414	−0.012	0.031
9.4750	−0.053	0.026
9.5083	−0.017	0.024
9.5417	0.013	0.026
9.5747	−0.028	0.031
9.6081	0.015	0.025
9.6417	0.006	0.022
1988 March 17	*Inf.*	V
9.0714	−0.004	0.012
9.0889	−0.004	0.017
9.1067	0.014	0.024
9.1333	0.004	0.026
9.1681	0.002	0.026
9.1997	0.005	0.025
9.2331	0.000	0.027
9.2664	0.008	0.023
9.2997	−0.016	0.018
9.3331	0.004	0.024
9.3664	−0.005	0.027
9.3997	0.000	0.023
9.4331	0.000	0.023

TABLE 2. (continued)

U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ	U.T.	Δm	σ
9.4664	−0.008	0.025	11.2331	0.403	0.008	12.9331	0.100	0.007	5.7721	0.037	0.005
9.5000	0.002	0.022	11.2667	0.396	0.009				5.8054	0.026	0.005
9.5333	0.024	0.018	11.3000	0.405	0.008	1988 May 17 *Sup.* *V*			5.8387	0.030	0.007
9.5664	0.011	0.021	11.3333	0.396	0.014				5.8724	0.035	0.007
9.5997	0.004	0.025	11.3667	0.398	0.013	3.9054	0.141	0.003	5.9054	0.004	0.010
9.6331	0.011	0.026	11.4008	0.416	0.014	3.9387	0.148	0.004	5.9387	0.010	0.019
9.6664	0.017	0.025	11.4331	0.406	0.013	3.9721	0.130	0.008	6.1390	−0.023	0.019
9.6997	0.019	0.022	11.4664	0.406	0.014	4.0054	0.142	0.008	6.3242	−0.002	0.019
9.7333	0.019	0.019	11.5000	0.407	0.008	4.0721	0.158	0.014	6.4429	−0.010	0.005
9.7664	0.015	0.015	11.5333	0.389	0.008	4.1054	0.159	0.022	6.4721	0.009	0.007
9.7997	0.044	0.012	11.5664	0.414	0.008	4.2057	0.155	0.018	6.5054	−0.017	0.011
9.8331	0.040	0.014	11.6000	0.401	0.009	4.2390	0.154	0.014	6.5721	0.005	0.012
9.8664	0.061	0.017	11.6333	0.400	0.008	4.2721	0.158	0.012	6.6054	0.017	0.012
9.8997	0.052	0.015	11.6664	0.407	0.009	4.3054	0.162	0.013	6.6387	−0.001	0.010
9.9331	0.063	0.015	11.6997	0.406	0.015	4.3721	0.169	0.015	6.6721	0.008	0.006
9.9664	0.081	0.020	11.7333	0.390	0.013	4.4057	0.160	0.015	6.7054	0.011	0.005
10.0000	0.095	0.017	11.7664	0.397	0.012	4.4385	0.165	0.009	6.7390	0.004	0.005
10.0331	0.084	0.012	11.8000	0.408	0.018	4.4721	0.162	0.010	6.7721	−0.003	0.004
10.0664	0.112	0.014	11.8331	0.395	0.018	4.5054	0.167	0.011	6.8054	−0.019	0.006
10.0997	0.119	0.020	11.8667	0.390	0.012	4.5387	0.172	0.011	6.8387	0.016	0.006
10.1331	0.121	0.015	11.9000	0.386	0.012	4.5721	0.146	0.015	6.8721	0.008	0.007
10.1667	0.127	0.014	11.9331	0.377	0.015	4.6054	0.156	0.021	6.9054	0.021	0.003
10.2003	0.158	0.013	11.9667	0.379	0.015	4.7054	0.156	0.029	6.9387	0.029	0.005
10.2331	0.153	0.014	12.0000	0.369	0.018	4.8054	0.150	0.021	6.9724	0.024	0.005
10.2664	0.158	0.008	12.0333	0.369	0.021	4.8387	0.137	0.017	7.0054	0.029	0.005
10.2997	0.174	0.010	12.0667	0.355	0.023	4.8721	0.136	0.010	7.0387	0.021	0.005
10.3331	0.173	0.011	12.1000	0.351	0.021	4.9054	0.147	0.010	7.0724	0.027	0.005
10.3664	0.192	0.012	12.1333	0.337	0.015	4.9387	0.139	0.009	7.1387	0.024	0.005
10.3997	0.191	0.010	12.1664	0.328	0.012	4.9721	0.134	0.011	7.1724	0.034	0.006
10.4331	0.193	0.009	12.2000	0.315	0.009	5.0054	0.125	0.012	7.2054	0.026	0.005
10.4664	0.211	0.006	12.2331	0.306	0.008	5.0721	0.118	0.011	7.2387	0.033	0.006
10.5000	0.220	0.005	12.2664	0.299	0.008	5.1057	0.110	0.011	7.2721	0.050	0.011
10.5333	0.237	0.005	12.3000	0.293	0.010	5.1387	0.117	0.008	7.3054	0.044	0.010
10.5664	0.245	0.005	12.3333	0.294	0.010	5.1721	0.113	0.009	7.3390	0.046	0.010
10.6003	0.250	0.005	12.3667	0.274	0.009	5.2054	0.108	0.009	7.3721	0.041	0.014
10.6331	0.263	0.006	12.4000	0.271	0.009	5.2387	0.105	0.008	7.4054	0.029	0.005
10.6664	0.269	0.013	12.4333	0.253	0.008	5.2721	0.094	0.010	7.4721	0.033	0.005
10.6997	0.282	0.020	12.4692	0.237	0.009	5.3054	0.105	0.009	7.5054	0.034	0.009
10.7333	0.284	0.020	12.5000	0.227	0.008	5.3387	0.093	0.008	7.5387	0.024	0.005
10.7664	0.287	0.021	12.5333	0.217	0.011	5.3721	0.091	0.007	7.5721	0.005	0.005
10.8000	0.310	0.020	12.5667	0.210	0.014	5.4054	0.069	0.007	7.6057	0.019	0.005
10.8347	0.323	0.015	12.5997	0.206	0.016	5.4387	0.069	0.005	7.6387	0.038	0.009
10.8664	0.318	0.014	12.6333	0.197	0.017	5.4721	0.081	0.005	7.6721	0.014	0.005
10.9331	0.345	0.014	12.6667	0.186	0.017	5.5054	0.056	0.005	7.7054	0.027	0.019
10.9664	0.336	0.013	12.6997	0.168	0.015	5.5390	0.051	0.005	7.7387	0.019	0.005
11.0000	0.344	0.013	12.7333	0.179	0.012	5.5721	0.048	0.008	7.7724	0.032	0.018
11.0331	0.368	0.019	12.7667	0.163	0.010	5.6054	0.067	0.012	7.8054	0.024	0.013
11.0664	0.374	0.012	12.7997	0.141	0.006	5.6387	0.050	0.011	7.8387	0.031	0.009
11.1000	0.373	0.014	12.8331	0.132	0.008	5.6721	0.047	0.011	7.8721	0.038	0.005
11.1664	0.409	0.014	12.8664	0.122	0.007	5.7057	0.036	0.012	7.9054	0.031	0.005
11.2000	0.390	0.014	12.8997	0.111	0.007	5.7390	0.043	0.009	7.9387	0.036	0.008

TABLE 2. (continued)

U.T.	Δm	σ
7.9721	0.034	0.007
8.0054	0.037	0.006
8.0390	0.052	0.005
8.0721	0.036	0.010
8.1054	−0.002	0.005
1988 June 05	*Sup.*	*V*
5.3483	0.008	0.003
5.3694	0.013	0.004
5.4000	0.013	0.009
5.4344	0.009	0.009
5.4683	0.028	0.009
5.5011	0.007	0.008
5.5344	−0.002	0.008
5.5678	−0.031	0.005
5.6017	−0.001	0.005
5.6356	0.004	0.006
5.6689	0.004	0.007
5.7022	−0.026	0.008
5.7369	−0.019	0.008
5.7689	−0.007	0.009
5.8017	−0.034	0.010
5.8353	−0.041	0.009
5.8683	−0.043	0.008
5.9017	−0.002	0.007
5.9350	0.001	0.007
5.9683	0.023	0.011
6.0025	0.038	0.011
6.0350	0.072	0.012
6.0683	0.066	0.012
6.1014	0.099	0.012
6.1350	0.116	0.006
6.1683	0.088	0.009
6.2017	0.091	0.008
6.2350	0.098	0.008
6.2683	0.092	0.008
6.3017	0.133	0.008
6.3350	0.108	0.005
6.3683	0.141	0.006
6.4017	0.134	0.006
6.4350	0.134	0.006
6.4683	0.140	0.005
6.5017	0.145	0.005
6.5350	0.160	0.005
6.5681	0.163	0.011
6.6014	0.151	0.011
6.6347	0.180	0.014
6.6714	0.169	0.017
6.7014	0.200	0.017
6.7344	0.179	0.012

U.T.	Δm	σ
6.7678	0.184	0.013
6.8014	0.175	0.010
6.8333	0.189	0.008
6.8667	0.210	0.008
6.9000	0.189	0.015
6.9333	0.184	0.015
6.9667	0.196	0.021
6.9997	0.193	0.020
7.0333	0.208	0.024
7.0667	0.240	0.021
7.1000	0.232	0.027
7.1333	0.232	0.021
7.1675	0.195	0.021
7.2000	0.193	0.016
7.2333	0.183	0.011
7.2667	0.180	0.004
7.3000	0.186	0.005
7.3333	0.188	0.005
7.3667	0.154	0.005
7.4000	0.164	0.005
7.4333	0.161	0.005
7.4667	0.182	0.005
7.5003	0.149	0.006
7.5333	0.146	0.006
7.5667	0.149	0.006
7.6000	0.143	0.015
7.6333	0.150	0.016
7.6667	0.184	0.026
7.7000	0.157	0.027
7.7333	0.153	0.013
7.7667	0.153	0.009
7.8000	0.153	0.009
7.8339	0.142	0.004
7.8667	0.170	0.009
7.9000	0.189	0.013
7.9333	0.186	0.018
7.9667	0.181	0.018
8.0000	0.189	0.019
8.0333	0.176	0.013
8.0667	0.174	0.009
8.1000	0.165	0.004
8.1333	0.181	0.009
8.1667	0.216	0.008
8.2000	0.192	0.016
8.2333	0.182	0.014
8.2667	0.177	0.015
8.3333	0.194	0.005
8.3664	0.185	0.005
8.4000	0.185	0.006
8.4333	0.166	0.006
8.4667	0.164	0.005

U.T.	Δm	σ
8.5000	0.163	0.008
8.6000	0.187	0.010
8.6333	0.171	0.012
8.6667	0.179	0.012
8.7000	0.175	0.006
8.7350	0.194	0.013
8.7667	0.171	0.017
8.8000	0.192	0.016
8.8333	0.159	0.016
8.8667	0.148	0.017
8.9000	0.168	0.009
8.9333	0.184	0.004
8.9667	0.175	0.005
8.9997	0.138	0.005
9.0333	0.126	0.005
9.0667	0.136	0.005
9.1000	0.146	0.007
9.1333	0.140	0.009
9.1664	0.105	0.010
9.2000	0.100	0.009
9.2331	0.124	0.009
9.2667	0.149	0.007
9.2997	0.118	0.010
9.3331	0.059	0.011
9.3664	0.073	0.011
9.4000	0.061	0.011
9.4333	0.108	0.015
9.4667	0.079	0.011
9.4997	0.056	0.013
9.5331	0.046	0.016
9.5667	0.035	0.017
9.5997	0.050	0.016
9.6333	0.048	0.017
9.6667	0.070	0.015
9.7000	0.026	0.015
9.7331	0.015	0.013
9.7667	0.021	0.013
9.8000	0.026	0.013
9.8333	−0.004	0.011
9.8667	0.019	0.011
9.9000	0.015	0.015
9.9333	0.045	0.014
9.9664	−0.009	0.015
9.9997	−0.008	0.015
10.0333	0.015	0.015
10.0720	−0.018	0.013
10.0997	0.036	0.013
10.1331	0.025	0.010
10.1664	0.035	0.013
10.2000	−0.010	0.011

U.T.	Δm	σ
1990 June 19	*Inf.*	*V*
6.5253	0.011	0.006
6.6644	−0.001	0.007
6.7908	−0.010	0.010
6.8261	−0.002	0.009
8.0044	−0.010	0.010
8.0553	0.003	0.009
8.1014	−0.002	0.010
8.1325	0.008	0.009
8.2611	−0.004	0.010
8.3083	0.006	0.011
8.3344	−0.010	0.012
8.3656	−0.003	0.012
8.4139	0.000	0.013
8.4472	−0.002	0.013
8.4764	−0.003	0.013
8.5369	−0.010	0.012
8.5733	−0.012	0.011
8.6031	−0.008	0.009
8.6361	−0.011	0.008
8.6731	−0.004	0.005
8.7347	−0.006	0.005
8.7653	−0.009	0.004
8.8236	−0.007	0.004
8.8736	−0.006	0.003
8.9197	0.009	0.006
8.9569	0.005	0.006
8.9903	0.008	0.006
9.0194	0.005	0.006
9.0514	0.009	0.009
9.0847	0.021	0.007
9.1069	0.036	0.007
9.1750	0.036	0.010
9.2069	0.035	0.012
9.2458	0.042	0.014
9.2736	0.056	0.018
9.3069	0.068	0.017
9.3500	0.080	0.015
9.3986	0.067	0.012
9.4519	0.067	0.010
9.4931	0.076	0.008
9.5264	0.074	0.010
9.5597	0.084	0.009
9.5958	0.080	0.010
9.6292	0.088	0.010
9.6764	0.087	0.013
9.7125	0.078	0.015
9.7486	0.061	0.015
9.7972	0.023	0.014
9.8389	0.038	0.015

"hot" or dead pixels, bad CCD columns, etc. were in our data field. Each point on the light curve was constructed by calculating from each image the ratio of the total DNs from Pluto/Charon and the sum of the total DNs from the comparison stars. Ratios of the two comparison stars were also computed for each image to confirm that they were nonvariable sources throughout the night (typically, the total scatter for the stars was 1%–2% on photometric nights and 3%–5% on the nonphotometric nights we observed). The ratio of the brightness of Pluto/Charon to the standard stars was converted to a magnitude scale with the zero point defined as the average of several clearly uneclipsed observations (see Table 1 for a list of the specific frames used for the zero point in each event). For all events, we were able to observe the system out of eclipse. One-sigma errors for each point due to (1) the individual photon statistics of Pluto/Charon, the two standard stars, and the sky background, and (2) the read noise of the detector (8 e^-) were computed following the techniques of Howell & Mitchell (1988) and are listed in Table 2. For three events (1986 June 8 and 27, and the last hour of 1988 June 5) the actual errors appear to be significantly higher. We attribute this discrepancy to the following sources of error not accounted for in our analysis: (1986 June 8) drift in the telescope pointing, in the wake of a total failure of the system later in the evening; (June 27) smoke due to a forest fire about two miles from the telescope; (June 5) airmasses between 2.5 and 4.1 combined with a moon within five days of full phase.

3. RESULTS

Our criteria for selecting events to observe was that at least half the event was observable before the onset of astronomical twilight, at less than 2.0 airmasses, and with the moon not within four days of full phase. Of 27 nights for which we were granted telescope time, successful observations were acquired for 15 (see Table 1). All the unsuccessful nights were lost to bad weather. One equipment failure, in the telescope's pointing system, occurred on 1986 June 8; we were still able to obtain part of the descending portion of the light curve and Pluto/Charon uneclipsed. Two full events were observed: one on 1986 April 5 and one on 1988 June 5. Three pairs of events, in which a superior event was followed by the corresponding inferior event (or vice versa), were observed: 1986 April 5 and 8, June 8 and 11, and March 14 and 17. Since we present *all* data obtained, unaveraged and unedited, including two events observed on nonphotometric nights and one observed during a local forest fire (1986 June 27), the quality of the data does vary. Even with data obtained under these less than ideal observing conditions, rudimentary information such as time of contacts can be derived, or the data can be used to check modeling results.

The measurements for each light curve, including the Universal Times of each image (recorded for the middle of each exposure), change in magnitude with respect to the uneclipsed light curve, and associated one-sigma error, are listed in Table 2. Each event is plotted in Fig. 1 on a common scale in both magnitude and time.

1985 January 16. The observation of this first event went initially unreported because the predicted timing for it (based on a preliminary orbit solution) was almost 3 h (five sigma) later than that observed, and because of our belief that the detector may have warmed up due to a low supply of liquid nitrogen in the dewar (this fear proved to be unfounded). The observation was confirmed when a second mutual event was detected the next month at times in agreement with it (Binzel *et al.* 1985). The data have been published graphically in the paper reporting the first detections of the mutual events (Binzel *et al.* 1985); the digital data are listed in Table 2. Preliminary modeling of this event has been reported in Dunbar & Tedesco (1986).

1985 April 9. Because this event occurred during a cirrusy period with a gibbous moon 2.5 h from Pluto, the data were obtained in the *R* filter, which is centered near the maximum sensitivity of the CCD and is less sensitive to scattered light. Further modeling efforts will reveal whether an event occurred on this night.

1986 March 4. After some initial alto-cumulus before local midnight, the sky cleared to photometric conditions for the duration of this superior event. Midpoint and egress are clearly visible, as is the slope of the background light curve at a rotational phase of ~0.75.

1986 March 20. Photometric conditions prevailed throughout the duration of this inferior event, for which midpoint and egress can be determined to an accuracy of a few minutes. A depth that is greater by nearly 0.15 mag in comparison with the 1986 March 4 and April 5 events demonstrates that Charon is significantly darker than Pluto, a point first made by Binzel *et al.* (1985) and first quantified by Dunbar & Tedesco (1986), and later by Tholen *et al.* (1987a), Binzel (1989), and Buie *et al.* (1992).

1986 April 5. This event was the first entire superior occultation we were able to observe from Palomar. It was also the first of three pairs of successive mutual occultation-transit events we observed, in which complementary events were observed in the same Charon "lunation." Conditions throughout the first half of the night were clear, with cirrus moving in towards the morning. The gap in data at ~9 UT was caused by a refill of the dewar with liquid nitrogen.

1986 April 8. Only ingress is observable for this event occurring right before dawn. The background light curve slope is essentially flat for inferior events, which occur at a rotational phase of ~0.25.

1986 June 8. Our observations on this clear night were cut short about one half hour after the event's predicted midpoint by the only equipment failure we experienced during the six years of our observational program, a malfunction in the control of the telescope's sidereal drive system. The system was fixed before the end of the night by the engineering staff at Palomar Observatory so that we were able to obtain baseline observations of Pluto/Charon one half hour after the predicted end of the event. The companion inferior event to this superior event was observed on June 11.

1986 June 11. Only first contact is observable for this event, which occurred as Pluto was setting. Cirrus and high, variable humidity throughout the night accounts for the large error bars.

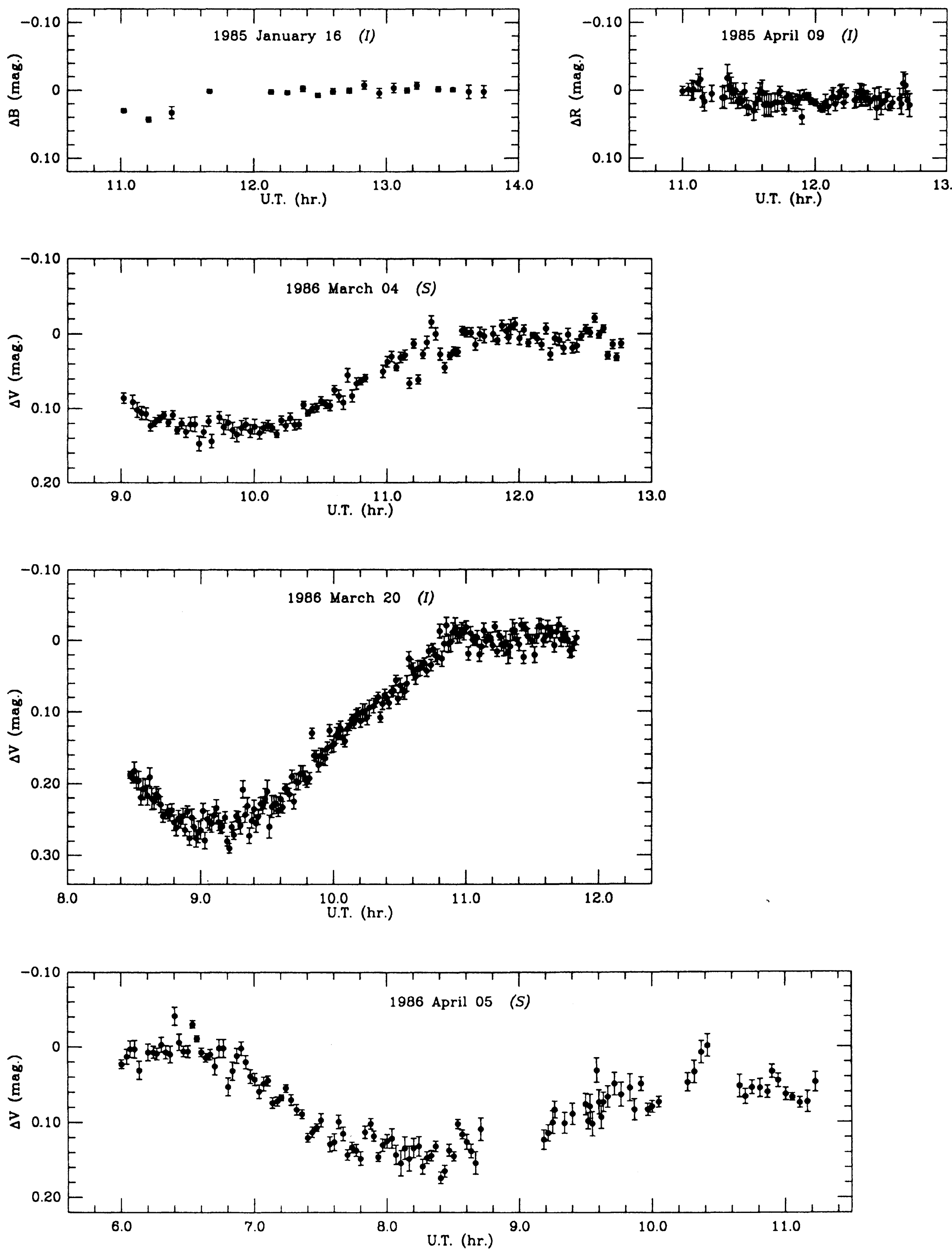

FIG. 1. Light curves for all the mutual events listed in Table 1. All observations were obtained in the *V* filter, except for the nights of 1985 January 16 and April 9, which were obtained in the *B* and Gunn *R* filters, respectively. Each event has been referenced to the unneclipsed portion of the light curve; the data points used to compute the zero point for each event are listed in Table 1.

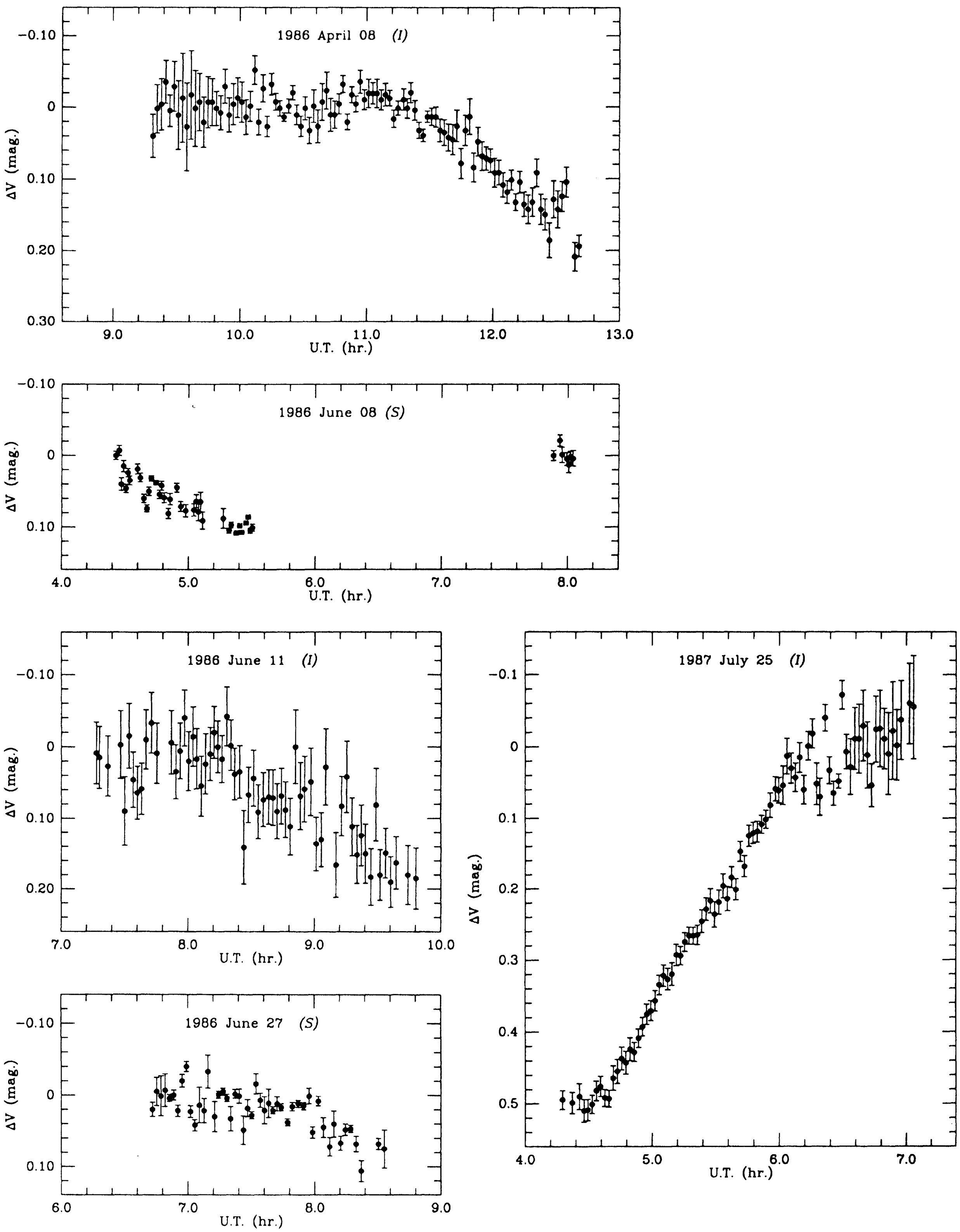

FIG. 1. (continued)

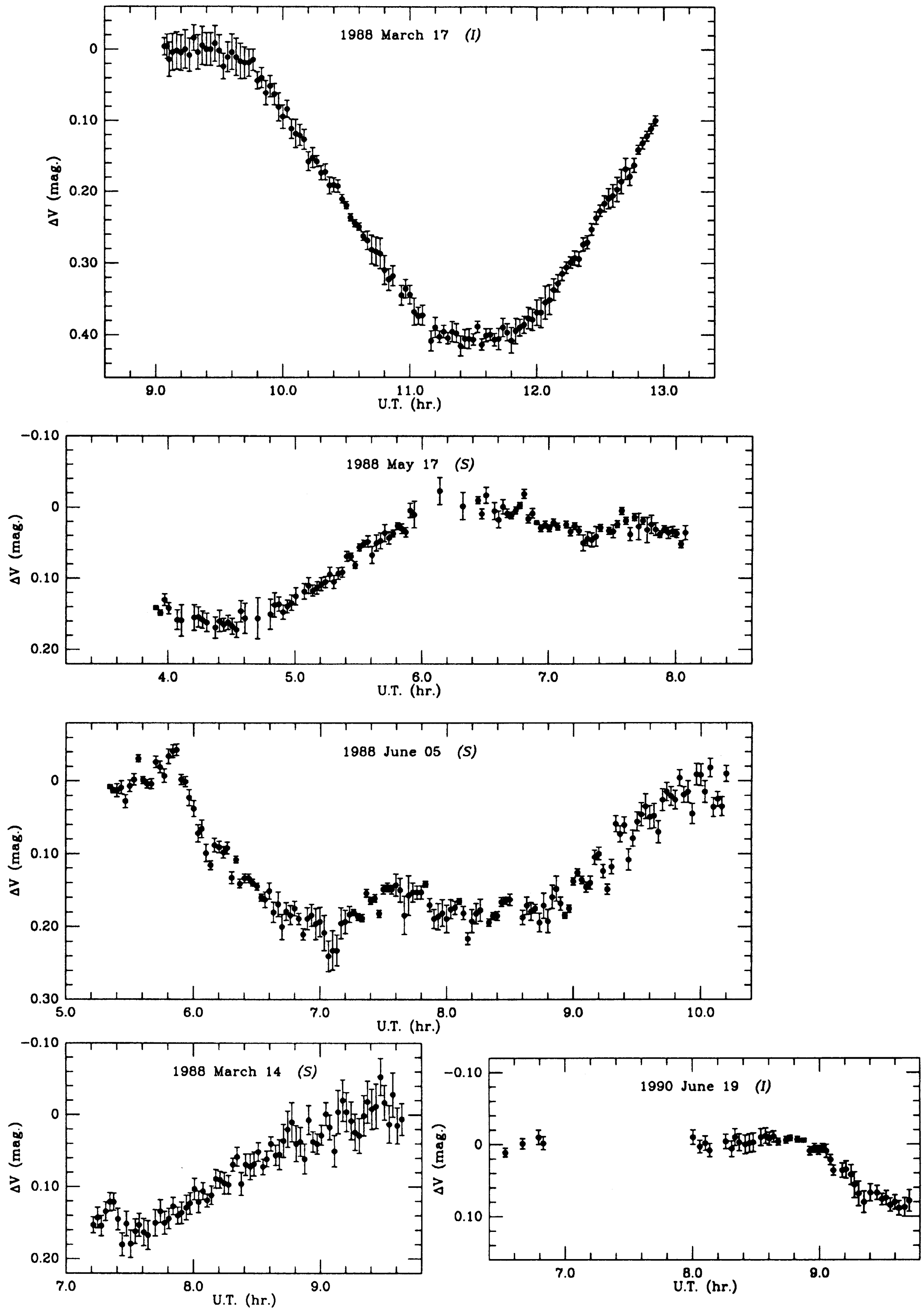

FIG. 1. (continued)

1986 June 27. Sky conditions were significantly degraded during this event due to a forest fire several miles away. First contact occurred nearly one hour later than preliminary predictions based on orbit modeling from the early events (Tholen 1985).

1987 July 25. In 1987 the addition of a new 800×800 TI Model 335 CCD detector to the camera resulted in significantly better signal to noise. This event was the first total transit we observed in the Pluto/Charon system, in which the full disk of Charon moved in front of Pluto. Third contact can be determined with an accuracy of a few minutes, but the last contact is less certain due to observing through an airmass of ~3.

1988 March 14. This event and the next one are the third pair of successive mutual occultation-transit events we observed, in which Charon moved in front and back of Pluto in the same orbital period.

1988 March 17. This event was observed nearly in its entirety on a photometric night. The relatively large error bars are due to the high airmasses.

1988 May 17. Third and fourth contact were obtained for this superior event. An unexpected increase in signal was observed towards the midpoint of the event [the predicted time of the second contact was 03:07 (Tholen *et al.* 1987b)]. We obtained a superior event 19 days later which suggests the increase is real. However, it remains unconfirmed until additional observations of superior events from this year are published (none have yet been).

1988 June 5. This was the second mutual superior event observed in its entirety. The feature near the midpoint of the event, which was first detected on May 17, is shown to be nearly 0.1 mag, and, if confirmed, would indicate the existence of a higher albedo region on Charon.

1990 June 19. First contact and midpoint were observed for this inferior grazing event. The depth of the event is nearly twice the published predicted one of 0.05 (Tholen & Buie 1989), but it is similar to that of the only other published inferior event of that year (Young & Binzel 1993).

4. CONCLUSIONS

In this paper we present photometric measurements for 15 eclipses which occurred during the Pluto–Charon mutual event season. The instrumentation for this project was kept as uniform as possible so that systematic experimental effects would not appear as spurious results in analysis and modeling of the data. These observations represent the most extensive set of mutual events yet published.

A fit of the events on 1986 March 4 and 20, and 1988 March 17 and June 5 with the published analytical model of Dunbar & Tedesco (1986) (Paper I of this series), and the Beletic *et al.* (1989) orbit radius of 19 640, yield radii of 1155±20 km for Pluto and 612±30 km for Charon. These results are in agreement with other published results based on the mutual events (Tholen *et al.* 1987a; Buie *et al.* 1992), but the radius for Pluto is lower than that derived from stellar occultation events (Elliot & Young 1992). A recent paper (Tholen & Buie 1995) eliminates some of this discrepancy with improved orbital elements for the system. The Dunbar and Tedesco model yields a ratio of the albedos of Charon to Pluto of 0.55 in 1986 and 0.70 in 1988. This result corresponds to a 27% lower albedo for the Charon-facing northern hemisphere of Pluto (we use the spin vector sense of north), in rough agreement with albedo maps produced from numerical models (Buie *et al.* 1992; Young & Binzel 1993).

The differences in visual albedo between the north and south pole of Pluto are similar to those found on Triton. McEwen's (1990) disk-resolved analysis of visual albedo differences on Triton based on Voyager imaging observations showed that the southern polar regions of Triton are about 35% higher in albedo than the northern polar regions. If one assumes that bright regions are areas of recently deposited frost, then it is true that both Pluto and Triton exhibit the least evidence of sublimation in regions which are currently under the strongest insolation. Recent work has shown that volatile migration has indeed occurred on Triton during the past 40 yr (Buratti *et al.* 1994). Given the similarity between Pluto and Triton, it would be useful to regularly obtain rotational light curves of Pluto to detect possible volatile migration.

We thank the Time Allocation Committee of Palomar Observatory, led by G. Neugebauer and R. Brucato, for their strong support of this program. The night assistant B. Staples and engineering staff, especially D. Tennant and J. Henning, were extremely helpful throughout the course of the Pluto–Charon eclipse season. R. Nelson was one of the observers for the 1986 March 20 event. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Observations were made at the 60 in. telescope at Palomar Mountain which is jointly owned by the California Institute of Technology and the Carnegie Institute of Washington.

REFERENCES

Albrecht, R., *et al.* 1991, ApJ, 374, L65
Andersson, L. E. 1978, BAAS, 10, 586
Beletic, J. W., Goody, R. M., & Tholen, D. J. 1989, Icarus, 79, 38
Binzel, R. P. 1989, G. R. L., 16, 1205
Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B. J., & Nelson, R. M. 1985, Science, 228, 1193
Blanco, C., Di Martino, M., & Ferreri, W. 1989, AJ, 98, 331
Blanco, C., Di Martino, M., & Ferreri, W. 1991, AJ, 101, 2262
Blanco, C., Di Martino, M., & Ferreri, W. 1994, AJ, 108, 1940
Buie, M. W., & Tholen, D. J. 1989, Icarus, 79, 23
Buie, M. W., Tholen, D. J., & Horne, K. 1992, Icarus, 97, 211
Buratti, B., Goguen, J., Gibson, J., & Mosher, J. 1995, Icarus, 110, 303
Burwitz, V., Reinsch, K., Pakull, M. W., Bouchet P. 1991, Eso Messenger, 66, 23
Christy, J. W., & Harrington, R. S. 1978, AJ, 83, 1005
Dunbar, R. S., & Tedesco, E. F. 1986, AJ, 92, 1201
Elliot, J., & Young, L. 1992, AJ, 103, 991
Howell, S. B., & Mitchell, K. J. 1988, AJ, 95, 247

Marcialis, R. L. 1988, AJ, 95, 941
Marcialis, R. L., & Lebofsky, L. A. 1991, Icarus, 89, 255
McEwen, A. S. 1990, G. R. L., 17, 1765
Reinsch, K., & Pakull, M. W. 1987, A&A, 177, L43
Stern, S. A. 1991, Icarus, 90, 271
Stern, S. A., & Trafton, L. A. 1984, Icarus, 57, 231
Stern, S. A., Trafton, L. A., & Gladstone, G. R. 1988, Icarus, 75, 485
Tholen, D. J. 1985, AJ, 90, 2639
Tholen, D. J., Buie, M. W., Binzel, R. P., & Frueh, M. L. 1987a, Science, 237, 512
Tholen, D. J., Buie, M. W., & Swift, C. E. 1987b, AJ, 94, 1681
Tholen, D. J., & Buie, M. W. 1989, Ninth Planet News, 8, 2
Tholen, D. J., & Buie, M. W. 1990, BAAS, 22, 1129
Tholen, D. J., & Buie, M. W. 1995, Icarus (submitted)
Trafton, L. M. 1989, G. R. L., 16, 1213
Young, E. F., & Binzel, R. P. 1993, Icarus, 102, 134