CIRCUMSTANCES FOR PLUTO-CHARON MUTUAL EVENTS IN 1987

DAVID J. THOLEN, MARC W. BUIE, AND CATHERINE E. SWIFT[a]
Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, Hawaii 96822
Received 25 August 1986

ABSTRACT

Circumstances are tabulated for 88 Pluto-Charon mutual events occurring during the 1987 opposition. Charon is predicted to be completely obscured either by Pluto or Pluto's shadow during each passage behind Pluto this opposition, providing several opportunities to study Pluto uncontaminated by the light of Charon. The duration of these total events is predicted to be from 32 to 79 min. The mutual-event season is now expected to conclude during the 1990 opposition. Two new stars have been selected as comparison stars for events occurring prior to opposition in 1987; the primary star is located at R.A. $14^h47^m24\overset{s}{.}23$ and Dec. $+01°00'31\overset{''}{.}9$, and the check star is located at R.A. $14^h48^m20\overset{s}{.}69$ and Dec. $+01°09'28\overset{''}{.}2$ (mean equator and equinox of 1950.0). Standardization of the primary comparison stars used in 1985 and 1986 has yielded the following magnitudes: $B = 12.6044 \pm 0.0015$ and $V = 11.7956 \pm 0.0017$ (1985 Primary); $B = 13.1238 \pm 0.0008$ and $V = 12.3885 \pm 0.0014$ (1986 Primary).

I. INTRODUCTION

Twice during each 248 year orbit of the Sun, the orbital plane of Pluto's satellite Charon sweeps across the orbit of the Earth and presents an edge-on geometry to the Earth. Within a narrow range of angles on either side of an edge-on geometry, as determined by the sizes and separation of the two bodies, transits of Pluto by Charon and its shadow, plus occultations and eclipses of Charon by Pluto and its shadow, will occur. The current season of mutual events began in late 1984, and the first events were detected in early 1985 (Binzel *et al.* 1985). The best available orbital and physical parameters now indicate that the season will end while Pluto is in conjunction with the Sun in 1990 (Tholen *et al.* 1987). This paper details the events observable during the 1987 opposition.

With the launch of the *Hubble Space Telescope* delayed and with no spacecraft scheduled to fly past Pluto, these mutual events represent our best opportunity to learn a great deal about our solar system's outermost known planetary system. Although much has been gleaned from the first two years of events, more remains to be done. In particular, the southern hemispheres of both Pluto and Charon have not yet been occulted, so their albedos are not well known. The observations of event depths during the 1987 opposition will provide important information on the surface-albedo distributions of one hemisphere on each object. The measurements of event times and durations should further refine the determination of diameters and orbital parameters, some of which are not yet well determined, as well as the mean density of the system.

II. MUTUAL EVENTS IN 1987

Table I shows the circumstances for mutual events occurring during the 1987 opposition. The columns contain the following information:

1—UT date corresponding to the time of maximum depth
2—Universal Time of first contact (beginning of event)
3—Universal Time of second contact (beginning of totality)
4—Universal Time of third contact (end of totality)
5—Universal Time of fourth contact (end of event)
6—Universal Time of maximum depth or mid-totality
7—predicted depth of event in Johnson *B*
8—right ascension at time of maximum depth
9—declination at time of maximum depth
10—heliocentric distance in astronomical units
11—geocentric distance in astronomical units
12—phase angle in degrees
13—Johnson *B* magnitude (out of eclipse)
14—window duration for 30° north latitude
15—window duration for 30° south latitude
16—range of east longitudes from which event can be observed
17—type of event (superior or inferior)

Numbers in columns 2 and 3 printed in boldface refer to the time on the previous UT date; likewise, numbers in columns 4 and 5 printed in boldface refer to the time on the following UT date. The word totality, as used for columns 3 and 4, refers to the time when the surface area that is physically blocked from view or in shadow is constant. For a superior event, totality occurs when Charon is entirely blocked from view either by Pluto or Pluto's shadow. For an inferior event, both Charon and Charon's shadow must be encompassed by the disk of Pluto for totality to occur. If the geometry does not produce totality, the corresponding column entries are marked with a dash.

Column 13 lists the Johnson *B* magnitude of the uneclipsed system at the time of maximum depth. The Johnson *V* magnitude is 0.84 mag brighter.

As in our previous paper (Tholen 1985), the window durations in columns 14 and 15 represent the length of time Pluto is at an airmass of less than 2.5 while the Sun is below −18° altitude. The statement in Tholen (1985) that the window duration was the same for observatories at both 30° north and 30° south latitude neglected the fact that, unlike Pluto, the Sun is not always near the celestial equator throughout the opposition. The window length was, in fact, correct only for 30° north latitude. The inclusion of a separate column for 30° south latitude eliminates this deficiency in the format of Tholen (1985). Of course, the window length differs for other latitudes, and if more accurate information is required, site-specific ephemerides can be generated on request.

[a] Summer research assistant at the Institute for Astronomy; present address at California Institute of Technology, Pasadena, California 91125.

 0004-6256/87/010244-04$00.90

TABLE I. Circumstances for Pluto-Charon mutual events during the 1987 opposition.

UT Date	Contacts				Max. Depth		R.A. (1950.0)	DEC.	r	Δ	α	B	Windows		Long.	Event
	(1)	(2)	(3)	(4)	UT	Mag						Mag	30°N	30°S	Range	Type
1986 Dec 10	08:07	10:00	10:34	12:35	10:17	0.24	$14^h44^m09^s.9$	+00°53'51"	29.701	30.427	1.27	14.76	0:03	--	251-319	Sup
13	12:44	---	---	17:15	15:13	0.52	14 44 34.1	+00 52 56	29.701	30.392	1.34	14.86	0:16	--	178-250	Inf
16	17:22	19:06	19:57	21:52	19:32	0.24	14 44 57.4	+00 52 11	29.701	30.354	1.40	14.76	0:29	--	106-181	Sup
20	**21:59**	---	---	02:32	00:31	0.55	14 45 20.0	+00 51 33	29.700	30.315	1.47	14.86	0:47	--	32-112	Inf
23	02:37	04:18	05:18	07:09	04:48	0.24	14 45 41.6	+00 51 04	29.700	30.274	1.53	14.75	1:00	--	320- 43	Sup
26	07:14	---	---	11:48	09:47	0.57	14 46 02.5	+00 50 44	29.700	30.230	1.58	14.85	1:12	--	248-334	Inf
29	11:53	13:31	14:38	16:26	14:05	0.24	14 46 22.2	+00 50 32	29.699	30.186	1.64	14.75	1:25	--	176-265	Sup
1987 Jan 01	16:30	---	---	21:05	19:03	0.60	14 46 41.1	+00 50 30	29.699	30.139	1.68	14.85	1:37	--	103-196	Inf
04	21:09	22:46	23:57	**01:43**	23:21	0.24	14 46 58.7	+00 50 35	29.699	30.092	1.73	14.75	1:50	--	30-126	Sup
08	01:46	---	---	06:22	04:20	0.62	14 47 15.3	+00 50 49	29.699	30.042	1.77	14.85	2:06	0:02	317- 58	Inf
11	06:26	08:01	09:15	11:00	08:38	0.24	14 47 30.7	+00 51 11	29.698	29.993	1.80	14.74	2:18	0:16	244-348	Sup
14	11:03	---	---	15:39	13:36	0.64	14 47 45.0	+00 51 42	29.698	29.941	1.83	14.84	2:29	0:31	172-278	Inf
17	15:42	17:17	18:34	20:16	17:56	0.24	14 47 57.9	+00 52 20	29.698	29.890	1.86	14.74	2:41	0:45	100-209	Sup
20	20:20	---	---	**00:55**	22:52	0.65	14 48 09.7	+00 53 07	29.697	29.837	1.87	14.84	2:52	1:01	27-139	Inf
24	01:00	02:34	03:52	05:33	03:13	0.24	14 48 20.1	+00 54 00	29.697	29.784	1.89	14.73	3:06	1:20	313- 68	Sup
27	05:37	---	---	10:12	08:09	0.66	14 48 29.3	+00 55 02	29.697	29.731	1.90	14.83	3:17	1:36	241-359	Inf
30	10:17	11:51	13:10	14:50	12:30	0.24	14 48 37.1	+00 56 10	29.697	29.678	1.90	14.73	3:28	1:50	168-289	Sup
Feb 02	14:55	---	---	19:29	17:25	0.67	14 48 43.6	+00 57 26	29.696	29.624	1.90	14.82	3:37	2:06	96-219	Inf
05	19:35	21:09	22:28	**00:06**	21:48	0.24	14 48 48.6	+00 58 47	29.696	29.571	1.89	14.72	3:48	2:21	23-148	Sup
09	00:13	---	---	04:45	02:41	0.67	14 48 52.4	+01 00 16	29.696	29.518	1.88	14.81	4:01	2:41	310- 79	Inf
12	04:53	06:27	07:46	09:23	07:06	0.24	14 48 54.8	+01 01 50	29.695	29.466	1.86	14.71	4:11	2:56	237- 8	Sup
15	09:31	---	---	14:02	11:57	0.67	14 48 55.8	+01 03 30	29.695	29.414	1.84	14.80	4:20	3:11	165-297	Inf
18	14:11	15:45	17:04	18:40	16:24	0.24	14 48 55.5	+01 05 14	29.695	29.363	1.81	14.70	4:30	3:26	92-227	Sup
21	18:49	---	---	23:19	21:13	0.67	14 48 53.8	+01 07 04	29.695	29.314	1.77	14.80	4:38	3:40	20-157	Inf
25	**23:29**	01:03	02:22	03:57	01:43	0.24	14 48 50.8	+01 08 57	29.694	29.265	1.73	14.69	4:50	4:00	306- 86	Sup
28	04:08	---	---	08:36	06:30	0.66	14 48 46.5	+01 10 55	29.694	29.217	1.69	14.78	4:59	4:15	233- 15	Inf
Mar 03	08:48	10:22	11:40	13:15	11:01	0.24	14 48 40.9	+01 12 55	29.694	29.172	1.64	14.68	5:07	4:29	161-304	Sup
06	13:26	---	---	17:55	15:46	0.65	14 48 34.0	+01 15 00	29.694	29.127	1.59	14.77	5:16	4:43	87-234	Inf
09	18:06	19:41	20:59	22:33	20:20	0.24	14 48 26.0	+01 17 05	29.693	29.085	1.53	14.67	5:24	4:58	15-163	Sup
13	**22:45**	---	---	03:13	01:03	0.63	14 48 16.7	+01 19 14	29.693	29.044	1.47	14.76	5:35	5:17	301- 92	Inf
16	03:25	05:00	06:17	07:52	05:39	0.24	14 48 06.4	+01 21 22	29.693	29.005	1.40	14.66	5:43	5:31	228- 21	Sup
19	08:04	---	---	12:32	10:19	0.61	14 47 54.9	+01 23 32	29.692	28.969	1.34	14.75	5:51	5:45	156-310	Inf
22	12:44	14:21	15:35	17:11	14:58	0.24	14 47 42.4	+01 25 43	29.692	28.934	1.26	14.65	5:59	5:59	83-240	Sup
25	17:23	---	---	21:51	19:36	0.59	14 47 29.0	+01 27 53	29.692	28.902	1.19	14.74	6:08	6:12	9-171	Inf
29	**22:04**	**23:41**	00:53	02:29	00:17	0.24	14 47 14.6	+01 30 01	29.692	28.872	1.12	14.64	6:18	6:31	296-102	Sup
Apr 01	02:43	---	---	07:09	04:52	0.57	14 46 59.3	+01 32 10	29.691	28.845	1.04	14.73	6:26	6:45	223- 32	Inf
04	07:23	09:02	10:11	11:48	09:37	0.24	14 46 43.3	+01 34 16	29.691	28.820	0.96	14.63	6:34	6:59	150-323	Sup
07	12:01	---	---	16:28	14:09	0.54	14 46 26.5	+01 36 20	29.691	28.799	0.89	14.72	6:42	7:12	77-253	Inf
10	16:40	18:23	19:28	21:06	18:56	0.24	14 46 09.1	+01 38 21	29.691	28.779	0.82	14.62	6:49	7:26	5-184	Sup
13	21:18	---	---	**01:46**	23:26	0.52	14 45 51.1	+01 40 18	29.690	28.763	0.75	14.72	6:57	7:40	292-115	Inf
17	01:57	03:45	04:44	06:25	04:15	0.24	14 45 32.6	+01 42 12	29.690	28.749	0.69	14.61	7:04	7:58	219- 46	Sup
20	06:34	---	---	11:05	08:42	0.51	14 45 13.7	+01 44 01	29.690	28.739	0.63	14.71	7:17	8:11	145-337	Inf
23	11:13	13:07	13:59	15:43	13:33	0.24	14 44 54.3	+01 45 46	29.690	28.731	0.59	14.61	7:25	8:11	72-264	Sup
26	15:51	---	---	20:23	17:59	0.50	14 44 34.8	+01 47 25	29.689	28.726	0.57	14.71	7:33	8:10	359-191	Inf
29	20:30	22:29	23:13	**01:01**	22:51	0.24	14 44 14.9	+01 49 00	29.689	28.724	0.56	14.61	7:41	8:10	287-119	Sup
May 03	01:08	03:18	03:23	05:41	03:21	0.50	14 43 55.1	+01 50 27	29.689	28.725	0.58	14.71	7:32	8:10	214- 45	Inf
06	05:47	07:44	08:23	10:19	08:04	0.24	14 43 35.1	+01 51 49	29.688	28.728	0.61	14.61	7:25	8:10	142-332	Sup
09	10:25	---	---	14:58	12:45	0.51	14 43 15.2	+01 53 04	29.688	28.735	0.65	14.71	7:19	8:10	69-260	Inf
12	15:04	16:58	17:30	19:36	17:14	0.24	14 42 55.5	+01 54 12	29.688	28.745	0.71	14.61	7:13	8:10	356-188	Sup
15	19:41	---	---	**00:16**	22:06	0.51	14 42 35.9	+01 55 13	29.688	28.757	0.77	14.72	7:03	8:10	283-117	Inf
19	00:21	02:13	02:48	04:54	02:31	0.24	14 42 16.6	+01 56 06	29.687	28.772	0.84	14.62	6:44	8:10	210- 42	Sup
22	04:59	---	---	09:33	07:25	0.52	14 41 57.6	+01 56 52	29.687	28.790	0.92	14.72	6:29	8:10	137-330	Inf
25	09:38	11:29	12:07	14:11	11:48	0.24	14 41 39.1	+01 57 29	29.687	28.810	0.99	14.63	6:14	8:05	66-257	Sup
28	14:16	---	---	18:50	16:44	0.52	14 41 21.0	+01 57 59	29.687	28.833	1.07	14.73	5:59	7:54	356-185	Inf
31	18:55	20:45	21:26	23:28	21:05	0.24	14 41 03.6	+01 58 20	29.686	28.859	1.15	14.64	5:45	7:43	286-112	Sup
Jun 04	**23:33**	---	---	04:07	02:03	0.52	14 40 46.7	+01 58 32	29.686	28.887	1.22	14.74	5:26	7:27	216- 38	Inf
07	04:12	06:01	06:45	08:44	06:23	0.24	14 40 30.6	+01 58 36	29.686	28.917	1.29	14.65	5:12	7:15	147-326	Sup
10	08:50	---	---	13:23	11:22	0.53	14 40 15.1	+01 58 31	29.686	28.950	1.37	14.75	4:58	7:03	77-253	Inf
13	13:30	15:17	16:04	18:01	15:41	0.24	14 40 00.6	+01 58 18	29.685	28.984	1.43	14.66	4:44	6:51	8-180	Sup
16	18:08	---	---	22:40	20:40	0.53	14 39 46.8	+01 57 56	29.685	29.021	1.50	14.76	4:31	6:39	298-108	Inf
20	**22:47**	00:34	01:23	03:17	00:59	0.24	14 39 34.1	+01 57 26	29.685	29.059	1.56	14.67	4:13	6:22	229- 34	Sup
23	03:25	---	---	07:56	05:59	0.53	14 39 22.2	+01 56 47	29.685	29.100	1.62	14.77	4:01	6:10	159-322	Inf
26	08:05	09:50	10:42	12:34	10:16	0.24	14 39 11.4	+01 55 59	29.684	29.142	1.67	14.68	3:48	5:57	90-248	Sup
29	12:43	---	---	17:13	15:16	0.53	14 39 01.6	+01 55 03	29.684	29.185	1.72	14.78	3:36	5:44	20-176	Inf
Jul 02	17:23	19:07	20:01	21:50	19:34	0.24	14 38 53.0	+01 53 59	29.684	29.230	1.77	14.69	3:25	5:31	312-103	Sup
06	**22:01**	---	---	02:29	00:33	0.53	14 38 45.5	+01 52 46	29.684	29.277	1.81	14.79	3:09	5:14	242- 30	Inf
09	02:40	04:24	05:20	07:06	04:52	0.24	14 38 39.2	+01 51 26	29.683	29.324	1.85	14.70	2:58	5:01	173-317	Sup
12	07:18	---	---	11:45	09:51	0.53	14 38 34.0	+01 49 57	29.683	29.372	1.88	14.80	2:48	4:47	104-244	Inf
15	11:58	13:41	14:39	16:23	14:10	0.24	14 38 30.0	+01 48 22	29.683	29.421	1.90	14.71	2:37	4:35	35-171	Sup
18	16:36	---	---	21:02	19:08	0.54	14 38 27.3	+01 46 38	29.683	29.471	1.93	14.81	2:27	4:22	325- 99	Inf
21	21:16	22:58	23:58	**01:40**	23:28	0.24	14 38 25.8	+01 44 48	29.683	29.522	1.94	14.72	2:18	4:08	256- 26	Sup
25	01:54	---	---	06:20	04:24	0.54	14 38 25.6	+01 42 51	29.682	29.573	1.95	14.82	2:05	3:52	186-312	Inf
28	06:33	08:15	09:16	10:57	08:45	0.24	14 38 26.6	+01 40 47	29.682	29.624	1.96	14.72	1:57	3:38	117-240	Sup
31	11:12	---	---	15:36	13:41	0.54	14 38 29.0	+01 38 36	29.682	29.675	1.96	14.83	1:48	3:25	48-167	Inf
Aug 03	15:51	17:32	18:35	20:14	18:04	0.24	14 38 32.6	+01 36 21	29.682	29.726	1.96	14.73	1:39	3:12	339- 94	Sup
06	20:29	---	---	**00:54**	22:57	0.55	14 38 37.5	+01 33 59	29.681	29.778	1.95	14.84	1:30	2:59	269- 22	Inf
10	01:09	02:50	03:54	05:33	03:22	0.24	14 38 43.6	+01 31 32	29.681	29.828	1.93	14.74	1:19	2:41	200-308	Sup
13	05:47	---	---	10:12	08:14	0.55	14 38 51.1	+01 29 00	29.681	29.879	1.91	14.84	1:12	2:28	131-235	Inf
16	10:27	12:07	13:12	14:51	12:39	0.24	14 38 59.7	+01 26 23	29.681	29.928	1.89	14.74	1:04	2:15	62-162	Sup
19	15:05	---	---	19:30	17:30	0.56	14 39 09.6	+01 23 42	29.680	29.978	1.86	14.85	0:56	2:03	352- 90	Inf
22	19:45	21:24	22:31	**00:09**	21:58	0.24	14 39 20.7	+01 20 58	29.680	30.026	1.82	14.75	0:48	1:49	283- 17	Sup
26	00:23	---	---	04:48	02:46	0.56	14 39 33.1	+01 18 09	29.680	30.073	1.79	14.85	0:38	1:32	213-303	Inf
29	05:02	06:42	07:49	09:27	07:15	0.24	14 39 46.5	+01 15 18	29.680	30.119	1.74	14.75	0:31	1:19	144-231	Sup
Sep 01	09:40	---	---	14:07	12:01	0.57	14 40 01.2	+01 12 23	29.680	30.163	1.70	14.85	0:23	1:06	74-159	Inf
04	14:20	15:59	17:08	18:45	16:34	0.24	14 40 16.9	+01 09 27	29.679	30.207	1.64	14.75	0:16	0:54	5- 86	Sup
07	18:58	---	---	23:24	21:17	0.58	14 40 33.8	+01 06 29	29.679	30.248	1.59	14.86	0:09	0:40	296- 13	Inf
11	**23:38**	01:17	02:26	04:03	01:51	0.24	14 40 51.6	+01 03 30	29.679	30.289	1.53	14.76	--	0:23	227-299	Sup
14	04:16	---	---	08:42	06:33	0.58	14 41 10.5	+01 00 29	29.679	30.327	1.47	14.88	--	0:11	157-227	Inf

Unlike last year, in which the longitudes of visibility were in a 180° W to 180° E format, the longitudes in column 16 are in a 0° to 360° format, measured to the east. The range of longitudes depends on the latitude of the observer as well, and the table includes those longitudes from which a portion of an event is visible either from 30° north or 30° south latitude, but not necessarily both.

The orbital and physical parameters used to generate these circumstances are shown in Table II and are based on the analysis of data accumulated in 1985 and 1986 (Tholen *et al.* 1987). The uncertainties in the times of the events are now quite small, but the times of the various contacts involve parameters that are less certain than the period; in particular, the times of second and third contact could be in error by more than 20 min. The intrinsic uncertainties in the times listed in the table are on the order of 1–2 min, because the computations were performed with 1 min time resolution. Note that the event durations are all very close to 4.5 hr because Charon (or its shadow) is passing in front of or behind the central portion of Pluto (or its shadow).

The predicted depths of the events assume that the mean albedo of the occulted material in 1987 is the same as the mean albedo of the material occulted through 1986. Some of the previously unocculted material will be blocked from view in 1987, however, so the extrapolation of the current model to 1987 may yield predicted depths that will differ from those actually observed. In fact, we fully expect inferior events to be shallower than predicted, because the best available model for the surface-albedo distribution on Pluto shows the equatorial region to be darker than the poles (Buie and Tholen 1986).

As in 1986, the 1987 inferior events will be deepest when the Earth is near preopposition quadrature. Totality should occur this year, primarily during the superior events. The Charon:Pluto size ratio is particularly uncertain in the current model, however; the duration of totality will be shorter if the true size ratio is larger than currently believed, possibly resulting in some events being nontotal. As the Earth approaches opposition, the duration of totality will grow shorter because parallax will cause the center-to-center separation of Pluto and Charon to increase, thus causing the effective chord length to decrease. After opposition, the duration of totality will begin to increase slowly as Pluto's heliocentric motion causes the distance between the center of Charon and the center of Pluto's shadow to decrease. Inferior events will generally not be total, because both Charon and its shadow will not be encompassed by Pluto's projected disk. The current model predicts one exception, the event on May 3 near opposition, which is when the shadow offset is at a minimum. Model uncertainties could allow a couple of additional total inferior events on either side of opposition, or none at all. Predicted light curves and the corresponding geometries are shown in Fig. 1 for three representative times in 1987: preopposition quadrature, opposition, and postopposition quadrature.

TABLE II. Orbital and physical parameters used to generate the circumstances.

Semimajor axis	19 130 km	
Eccentricity	0.0	
Inclination	91°.6	mean equator and equinox of 1950
Ascending node	222°.44	mean equator and equinox of 1950
Argument of perihelion	0°.0	mean equator and equinox of 1950
Mean anomaly	259°.59	
Epoch	JD 2446600.5	
Period	6.387204 days	
Pluto radius	1145 km	
Charon radius	642 km	
Pluto blue geometric albedo of the occulted material	0.61	
Charon blue geometric albedo of the occulted material	0.42	

III. COMPARISON STARS

Once again, we have selected stars to be used as comparison stars for events occurring before opposition in 1987. Eighteen stars were observed on 1986 January 13 and 14 with the 2.24 m University of Hawaii telescope on Mauna Kea. The two having the best combination of brightness, color match, and proximity to Pluto were selected as comparison stars, with the brighter of the two being designated as the primary comparison of star. The positions of the two stars were measured on print copies of the Palomar Sky Survey; the accuracy of the positions is limited by the size of the unknown proper motions, not by the astrometry, which yielded residuals on the order of an arcsecond.

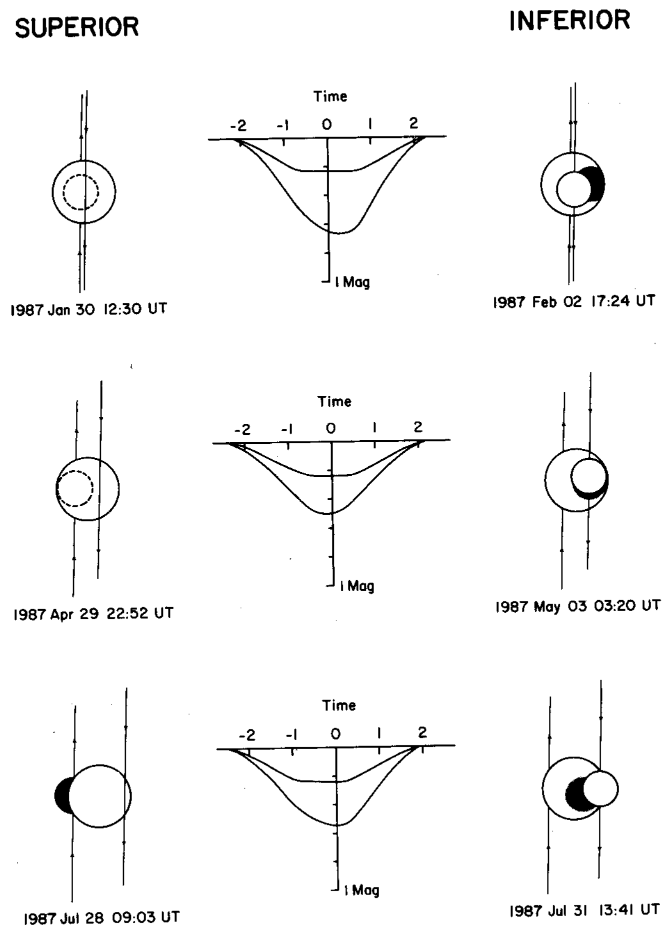

FIG. 1. The geometry of the Pluto-Charon system is shown in the leftmost and rightmost columns for three representative times in 1987: preopposition quadrature, opposition, and postopposition quadrature. Equatorial north is up in all views. The middle column contains the corresponding predicted light curves. The vertical axis corresponds to the time of minimum separation between Pluto and Charon; the horizontal axis is in hours from minimum separation. In all three cases, the flat-bottomed light curve corresponds to the superior event depicted on the left, while the rounded light curve corresponds to the inferior event depicted on the right.

TABLE III. Comparison stars for use in 1987.

Star	R. A. (1950.0)	Dec.	B	$B-V$
1986 Primary	$14^h38^m53^s.30$	$+02°01'09''.9$	13.12	0.74
1986 Check	$14^h39^m44^s.19$	$+02°04'07''.3$	13.52	0.74
1987 Primary	$14^h47^m24^s.23$	$+01°00'31''.9$	12.30	0.88
1987 Check	$14^h48^m20^s.69$	$+01°09'28''.2$	12.87	0.88

TABLE IV. Standard magnitudes for primary comparison stars used in 1986.

Star	B	V	$B-V$
	15	17	12
1985 Primary	12.6044	11.7956	0.8094
	8	14	11
1986 Primary	13.1238	12.3885	0.7352

The 1987 comparison stars are listed along with the 1986 stars in Table III. Pluto will be closer to the 1986 stars after opposition, so, beginning with the May 3 event, the 1986 stars should be used instead of the 1987 stars.

In addition to selecting comparison stars, we have been carefully standardizing comparison stars used in previous years. For accurate comparison of mutual-event data from different years, the magnitudes of the comparison stars need to be known to higher precision than the data on Pluto itself. Our goal has been to determine the magnitudes of the comparison stars to approximately 0.0010 mag relative to some adopted standard star.

During the 1986 opposition, we obtained ten nights of B and V photometry on comparison star 1985 Primary, plus 22 nights of B and 20 nights of V photometry on 1986 Primary. The weighted means and standard deviations of those means are shown in Table IV. The standard deviations are shown directly above the magnitudes in units of the last digit. The tabulated $B-V$ colors are not exactly equal to the differences between the B and V magnitudes because the mean colors were determined by calculating the weighted mean of the individual colors on each night; the discrepancies are smaller than the standard deviations themselves, however, and are quite insignificant.

For purposes of computing the standard magnitudes of these stars, we have chosen a photometric system in which the Johnson magnitudes and color of SAO 120107 are defined to be $B=9.8966$, $V=9.2400$, and $B-V=0.6566$. This definition was necessary because the Johnson system is not internally accurate to the millimag level; the assumed magnitudes and color for SAO 120107 are consistent with the established Johnson system, however, so we are not forcing a zero-point shift by defining SAO 120107 to have those values.

The peak-to-peak differences in the B magnitudes for 1985 Primary and 1986 Primary are 0.0118 and 0.0152 mag, respectively, with no systematic trend as a function of time, so we have no evidence of variability in either star. We are, however, continuing to monitor the brightnesses of all comparison stars to maintain an internally consistent system of the highest possible precision and to look for possible long-term variability. We plan to publish final results for these stars in a future paper. The results from 1986 are included here so that those who observed events in 1986 can reduce their observations to the same photometric system.

IV. COMMENTS

Some basic guidelines for observing these events were given previously (Tholen 1985). In addition to those guidelines, the following items are worth mentioning. Further refinement of the diameters of the bodies will come from the observations of the times of the contacts. Thus even a short observation (about an hour) can yield important information if one of the contacts occurs during the observation. Albedo variegation on Charon can be studied by the observations of the wings of the events between first and second or third and fourth contact. Any departures from a smooth ingress light curve should recur during egress, thus providing almost instant confirmation of any significant albedo features. Albedo variegation on Pluto is harder to study because of the steep slopes of the ingress and egress portions of the light curve; nevertheless, the maximum depth does yield the mean albedo of the occulted material, and as the occulted area changes from one event to the next, differences can be mapped out.

Between the second and third contacts of a superior event, Pluto can be studied uncontaminated by the light of Charon. Not only will the disk integrated albedos of each object's sunward hemisphere be determined, but a variety of spectroscopic and colorimetric observations can be obtained of Pluto only. Similar out-of-eclipse observations obtained immediately preceding or following a flat-bottomed superior event can, after removal of Pluto's contribution, yield the corresponding data for Charon.

More detailed predictions for any one event can be obtained by writing to the first author and specifying the nights and observatory coordinates for which more information is desired.

This work was supported by NASA grant No. NGL 12-001-057.

REFERENCES

Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B. J., and Nelson, R. M. (1985). Science **228**, 1193.

Buie, M. W., and Tholen, D. J. (1986). Bull. Am. Astron. Soc. **18**, 821.

Tholen, D. J. (1985). Astron. J. **90**, 2639.

Tholen, D. J., Buie, M. W., Binzel, R. P., and Frueh, M. L. (1987). In preparation.