OCCULTATIONS BY PLUTO AND CHARON: 1990–1999

DOUGLAS J. MINK
Harvard–Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138

ARNOLD R. KLEMOLA
UCO/Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz, California 95064

MARC W. BUIE[1]
Space Telescope Science Institute 3700 San Martin Drive, Baltimore, Maryland 21218
Received 8 March 1990; revised 8 February 1991

ABSTRACT

The results of a photographic plate search for stars as faint as $V = 16$ which may be occulted by Pluto or Charon between 1 January 1990 and 31 December 1999 are presented. Circumstances for the closest approach of Pluto to 32 stars and Charon to 28 stars are presented. Photometric information is given for some of the brightest stars found in a search of the *Space Telescope Guide Star Catalog* for Pluto occultations. Finding charts from Space Telescope Guide Star plates are provided for some of the best events. The brightest star ($V = 12.7$) may be occulted by both Pluto and Charon on 26 September 1999.

1. INTRODUCTION

Pluto is now on its way out from the Sun, having come closest to the Sun on 7 September 1989 (the Pluto–Charon barycenter was closest on 5 September 1989). The smallest known planet in the solar system and its satellite Charon are slowly yielding their secrets to Earth-based observations. Marcialis (1988) and Buie & Tholen (1989) have derived surface albedo maps from single point absolute photometry spanning a period of time from 1954 to 1986. Observations of mutual eclipses by Pluto and Charon (Binzel *et al.* 1985; Tholen *et al.* 1987, 1988) have provided information about Charon's orbit and the bulk density of the Pluto–Charon system. Stellar occultations, however, give instantaneous high spatial resolution views of that system, providing tests of models generated by analysis of other data.

Halliday (1963) first proposed conducting an ongoing search for occultations of stars by Pluto in order to determine its diameter. Observation of the event he predicted for 28 April 1965 (Halliday 1965) led to the establishment of an upper limit for Pluto's diameter of 6800 km (Halliday *et al.* 1966).

Taylor (1978) forecast the close approach of a 13th magnitude star to Pluto on 6 April 1980. Walker (1980) observed an occultation by Charon of that star which set a lower limit of 600 km for Charon's radius. A search of the *Palomar Sky Survey* covering Pluto's path from 1979 to 1985 (Shelus & Benedict 1978) turned up a promising event on 15 April 1982 which went unobserved. A close approach of Pluto to a 9th magnitude star on 4 April 1983, predicted by diCicco (reported by Millis & Wasserman 1983), was observed but no occultation was seen. Taylor (1984) reported four unobserved possible occultations by Pluto of faint stars in 1984.

Mink & Klemola (1985) searched plates for Pluto occultations between 1985 and 1990. Brosch & Mendelson (1985) observed the second event, MKP2, but the nature of their observation remains uncertain. It appears, using the current Pluto ephemeris, that they may have observed a grazing occultation by Pluto's extended atmosphere. On 9 June 1988, the occultation of MKP8, the eighth event in Mink & Klemola (1985), was recorded by numerous observers in the South Pacific (Blow & Priestly 1988; Elliot *et al.* 1988; Kilmartin *et al.* 1988; Mattram *et al.* 1988; Millis 1988; Page *et al.* 1988; Walker *et al.* 1988b; Watson *et al.* 1988), and indications of an atmosphere on Pluto were seen (Elliot *et al.* 1989; Walker *et al.* 1988a).

This paper carries the occultation search through 31 December 1999, past Pluto's resumption of its title as ninth planet from the Sun on 15 February of that year. As Pluto moves farther out, it will cool, and the structure and composition of its atmosphere may change. Additional occultation observations will monitor these changes. An occultation of Charon at higher time resolution or with multiple observatories will better determine it's shape and size.

2. ASTROMETRIC AND PHOTOMETRIC OBSERVATIONS: COARSE SELECTION

Photographic observations were made with the Lick 51 cm Carnegie astrograph, using 17×17 in. (6×6 deg) yellow-sensitive Kodak 103aG plates with GG 14 filter. All exposures were 60 min in length, permitting stars somewhat beyond yellow magnitude 16 to be measured. The five plates, overlapping by about one degree in right ascension, were taken on three nights for which the mean epoch is 1989.4. The maximum range for the trajectory of Pluto is 26 deg for the 10 yr interval surveyed. Currently Pluto is entering the Milky Way from Libra to Ophiuchus, with more numerous useful occultations compared to recent decades.

The search for occultation candidate stars was made in a way similar to our previous work (Mink & Klemola 1985). For the present survey a 10 day ephemeris of Pluto was computed using the JPL DE-130 ephemeris (Standish 1987) and used to identify candidate stars on the photographs, using the Lick Gaertner survey machine (Klemola *et al.* 1987).

[1] Visiting Astronomer, Cerro Tololo Inter-American Observatory, National Optical Astronomical Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

 0004-6256/91/062255-07$00.90

Most stars in a band 4–5 arcmin across were recorded almost to the plate limit. The purpose of selecting stars in such a wide band is to construct a catalog of secondary reference stars suitable for small field astrometry, such as with large reflector telescopes, possibly employing CCDs as detectors. An example of such use was a search for occultation candidates done at MIT (Dunham *et al.* 1990).

Subsequently, the surveyed stars were measured for precise rectangular coordinates and reduced to equatorial coordinates for equinox 1950 in a way similar to that employed in our earlier survey. Reference stars were taken from the PERTH 70 catalog (Høg & von der Heide 1976). Because of the weakness of images in the last magnitude above the plate limit, the derived coordinates for those stars are less certain.

Measurements with the Lick Gaertner automatic measuring machine (Klemola *et al.* 1987) also provide photometer readings. These have been converted to approximate V magnitudes, using mainly stars from the *Guide Star Photometric Catalog* (Lasker *et al.* 1988) for the *Hubble Space Telescope*. These stars occupy relatively small areas on Lick astrograph plates, so that needed position-dependent terms could not be included in the photometric reduction model. Consequently, our magnitudes should be regarded only as an approximate guide, particularly for the last magnitude, where extrapolation to the plate limit was required. There is some suggestion that our magnitudes may be too bright by about 0.5 mag for the faintest stars.

3. THE OCCULTATION SURVEY

The first result of the survey was a catalog of coordinates (B1950) and magnitudes for 6329 stars from the five separately reduced plates. This initial catalog was then merged internally and with the catalog generated in our 1985 survey by combining stars measured on overlapping plates. Stars with coordinates within 0.5 arcsec from overlapping plates were regarded as identical and the separate coordinates averaged. The resulting catalog of 5825 stars was searched for possible occultations by Pluto and by Charon. This plate catalog is available in ASCII format from D. Mink.

The resulting catalog was sorted by right ascension and put into a database format designed for rapid random access. The search was conducted in two stages. A coarse search for stars within 10 arcsec of the paths of Pluto and Charon associated specific stars with specific dates. This search also dropped those stars passed by Pluto and Charon when they will be within 45 degrees of the Sun. Exact occultation circumstances were computed for the remaining candidates, and those stars further than 2 arcsec from the paths of Pluto or Charon were dropped.

Tables 1 and 2 give the results of this search. The events are numbered sequentially in time, and those stars occulted by both Pluto and Charon have the same number. Photometric measurements have been made for those stars which were found in a search of the *Space Telescope Guide Star Catalog* by Mink & Buie (1989 and below). Due to a lack of time and some questions about the quality of the GSC positions, no search for Charon candidates was carried out until now. No offset has been added to the DE-130 ephemeris other than that appropriate for the orbits of Pluto and Charon around their common center of mass.

In the tables:

(i) Number is the event number continuing from our previous survey (Mink & Klemola 1985). Stars are numbered sequentially and preceded by a "P" when Pluto passes within 1 arcsec of the star and a "C" when Charon passes within 1 arcsec of the star.

(ii) Distance is the closest approach of the planet to the star in arcsec. "s" indicates that the star will appear to pass south of the planet, "n" that the star will pass north of the planet.

(iii) Velocity is that of Pluto relative to the star on the sky plane in km/s.

(iv) Sun Angle is the angular distance in degrees between the planet and the Sun as seen from Earth. Small numbers mean that the region on the Earth where Pluto is above the horizon and the Sun is below the horizon is small.

(v) Right ascension and declination are given in B1950 coordinates.

(vi) M_v is an approximate visual magnitude determined from the plate.

(vii) Region of Observability is a brief description of that part of the earth where Pluto is above the horizon and the Sun is below the horizon.

4. SPACE TELESCOPE GUIDE STAR SEARCH

In order to obtain aperture photometry of some of the candidate stars before the plates had been measured, a deep catalog of the appropriate part of the sky was needed. The *Space Telescope Guide Star Catalog* (Lasker *et al.* 1989), which contains stars from $V=7$ to fainter than $V=14$, was available at the Space Telescope Science Institute. The JPL DE-130 ephemeris was used to generate boxes containing Pluto's track through the sky for half a year at a time. These were written to an appropriately formatted file in Cambridge which was sent by computer network to Baltimore where it was used as input to the GSC search utility. A total of 46 461 entries were found in the search boxes, representing 23 575 point sources after duplicate entries from overlapping boxes were removed and positions from multiple plates were averaged. The remaining sources were sorted by right ascension, and a coarse search revealed 218 sources which Pluto would approach within 10 arcsec; 17 of those were approached within 2 arcsec. Due to an error in the software, the original search was incomplete, and only nine of those stars were found in the original search and selected for photometric observation. Of those nine, 5006.0365 and 5006.0320, which will be approached by Pluto on 26 January 1990 and 16 September 1991, respectively, turned out to be galaxies rather than stars. As such extended sources are hard to find and may be incompletely occulted, they have been dropped from the prediction tables.

5. PHOTOMETRY

The *Guide Star Catalog* search for Pluto occultation candidates yielded a total of nine stars. These stars were observed by M. Buie at visible wavelengths with the 1.5 m telescope at Cerro Tololo Inter-American Observatory on the night of 1989 May 28/29. Additional K-band observations were obtained by M. Buie at the United Kingdom Infrared Telescope on 1989 July 3.

The visible wavelength observations were obtained on the CTIO 1.5 m telescope at the $f/13.5$ Cassegrain focus using the People's Photometer with the Hamamatsu phototube, coldbox No. 71, and public filter set No. 3. The R and I filters

TABLE 1. Possible occultations by Pluto 1990–1999.

Number	Closest Approach Date	U.T.	Distance	Velocity (km/sec)	Sun Angle	α_{1950}	δ_{1950}	Mv	Region of Observability
	1990								
P10[a]	9 Jan	23:53	0.25s	21.2	63	15 14 25.440	-2 06 07.31	13.1	India
P11[a]	31 May	2:45	0.70n	21.3	152	15 09 16.333	-1 06 32.66	15.9	E. Americas
P12[a]	20 Jun	9:50	0.76s	16.5	134	15 07 29.799	-1 06 14.65	15.1	Central Pacific
P13[a]	5 Sep	14:49	0.58s	21.4	64	15 07 16.221	-1 48 20.30	15.4	India
	1991								
P14[a]	15 Sep	15:10	0.55n	24.1	57	15 17 03.742	-2 55 30.75	15.2	W.India
	1992								
P15[ab]	30 Jan	12:49	0.72s	14.6	78	15 34 05.532	-4 01 14.78	15.5	W. N.America
P16[a]	1 Mar	16:16	0.35n	7.1	108	15 34 59.050	-3 50 14.79	15.2	W. Pacific
P17[a]	21 May	6:19	0.20s	23.2	162	15 29 06.351	-3 11 38.97	14.3	N.+S.America, Hawaii
P18[a]	13 Sep	14:26	0.62n	22.6	61	15 25 56.817	-3 52 58.86	14.9	India
	1993								
P20	3 Oct	9:17	0.36n	28.5	45	15 36 50.527	-5 06 50.77	12.4	E.Australia, Japan
	1995								
P23	5 Jan	13:58	0.69n	27.6	47	15 58 53.032	-6 53 58.54	14.8	W. N.America
P24[a]	8 Jan	3:37	0.27s	26.7	49	15 59 11.331	-6 54 16.65	13.7	Africa, Middle East
P25[c]	13 Mar	8:03	0.85n	7.2	111	16 02 40.652	-6 41 25.66	15.0	E. N.America, S.America
P26	7 May	2:05	0.46n	22.6	161	15 59 04.826	-6 17 16.59	14.7	Europe, Africa, S.America
P27[d]	14 Jun	14:36	0.54n	21.1	152	15 55 03.783	-6 09 06.26	14.7	W. Pacific
P28[a]	6 Jul	3:26	0.25n	15.7	133	15 53 13.669	-6 10 46.87	15.7	E. Americas
	1996								
P29[a]	27 Feb	17:02	0.75n	6.6	95	16 11 53.104	-7 43 24.09	16.3	W. Pacific
P30[a]	17 Apr	3:44	0.16n	18.2	143	16 10 16.559	-7 23 12.39	16.4	Europe, Africa, S.America
P31[a]	28 Jul	2:32	0.86s	9.5	114	16 01 20.764	-7 15 35.67	14.5	E. N.America, S.America
P33	6 Sep	22:55	0.81s	15.5	76	16 01 41.582	-7 37 44.39	16.1	E. S.America
P34[a]	19 Sep	14:44	0.05s	20.7	65	16 02 31.159	-7 46 22.72	15.3	India
	1997								
P35	10 Jan	23:35	0.57n	27.2	47	16 17 32.029	-8 44 14.17	15.6	India
P36	22 Feb	11:33	0.84n	8.9	88	16 20 55.933	-8 40 00.42	15.6	W. N.America
P37	9 May	4:21	0.78s	22.3	159	16 17 43.528	-8 12 14.12	15.7	E. Americas
	1998								
P40	28 Feb	14:03	0.48n	7.4	92	16 30 15.914	-9 32 28.49	15.6	New Zealand, Hawaii
P42[a]	9 Jul	22:00	0.06s	16.8	137	16 21 01.635	-9 03 30.47	14.7	Africa, Europe
P44	21 Sep	15:19	0.45n	19.1	68	16 20 40.094	-9 36 36.84	15.7	India
	1999								
P45[a]	1 Feb	18:52	0.57s	0.4	63	16 37 43.506	-10 29 39.10	14.7	Australia
P46[a]	27 Feb	23:32	0.07s	8.5	89	16 39 22.097	-10 25 27.11	15.1	India, Central Asia
P47	25 May	1:06	0.33s	23.4	167	16 34 58.401	-9 59 31.00	15.2	Europe, Africa, S.America
P48[a]	11 Jul	22:49	0.57s	17.0	138	16 30 13.718	-9 58 51.54	15.6	Europe, Africa, S.America
P49[a]	26 Sep	1:01	0.25s	19.7	66	16 29 58.316	-10 32 05.73	12.7	W. S.America, Carribean

[a] possible occultation by Charon
[b] Extremely weak image with uncertain position.
[c] Star not seen on Palomar Sky Survey plates. Despite stellar appearance on the Lick astrograph plate, it could be a film defect or previously unknown variable star.
[d] Palomar Sky Survey plates show faint companion several arcseconds to the southeast.

TABLE 2. Possible occultations by Charon 1990–1999.

Number	Closest Approach Date	U.T.	Distance	Velocity (km/sec)	Sun Angle	α_{1950}	δ_{1950}	Mv	Region of Observability
	1990								
C10[a]	9 Jan	23:53	0.84s	21.2	63	15 14 25.440	-2 06 07.31	13.1	India
C11[a]	31 May	2:46	0.58n	21.3	152	15 09 16.333	-1 06 32.66	15.9	S.America, E. N.America
C12[a]	20 Jun	9:51	0.05n	16.5	134	15 07 29.799	-1 06 14.65	15.1	Australia, New Zealand, Hawaii
C13[a]	5 Sep	14:37	0.06n	21.4	64	15 07 16.221	-1 48 20.30	15.4	India
	1991								
C14[a]	15 Sep	15:10	0.33n	24.2	57	15 17 03.742	-2 55 30.75	15.2	India
	1992								
C15[ab]	30 Jan	12:53	0.21s	14.5	78	15 34 05.532	-4 01 14.78	15.5	W. N.America, Hawaii
C16[a]	1 Mar	17:02	0.43n	7.2	108	15 34 59.050	-3 50 14.79	15.2	W. Pacific
C17[a]	21 May	6:18	0.80s	23.1	162	15 29 06.351	-3 11 38.97	14.3	N.America, S.America, Hawaii
C18[a]	13 Sep	14:28	0.34n	22.7	61	15 25 56.817	-3 52 58.86	14.9	India
C19	27 Sep	19:39	0.60s	27.7	48	15 27 18.130	-4 04 48.34	15.3	W. Africa
	1994								
C21	15 May	10:53	0.35s	23.5	165	15 48 42.805	-5 14 52.89	14.9	Pacific Ocean
C22	18 May	16:08	0.86n	23.4	166	15 48 22.272	-5 13 52.03	14.8	W. Pacific, India
	1995								
C24[a]	8 Jan	3:41	0.23s	26.7	49	15 59 11.331	-6 54 16.65	13.7	Africa, Middle East
C28[a]	6 Jul	3:20	0.10n	15.7	133	15 53 13.669	-6 10 46.87	15.7	S.America, E. N.America
	1996								
C29[a]	27 Feb	17:02	0.27n	6.8	95	16 11 53.104	-7 43 24.09	16.3	W. Pacific
C30[a]	17 Apr	3:51	0.97n	18.3	143	16 10 16.559	-7 23 12.39	16.4	Atlantic, S.America
C31[a]	28 Jul	2:16	0.04s	9.6	114	16 01 20.764	-7 15 35.67	14.5	S.America, E. N.America
C32[c]	28 Jul	8:20	0.76s	9.5	114	16 01 20.270	-7 15 42.13	14.6	Hawaii, New Zealand, Australia
C34[a]	19 Sep	14:55	0.48s	20.6	65	16 02 31.159	-7 46 22.72	15.3	India
	1997								
C38	4 Jun	22:23	0.88s	23.1	163	16 14 53.687	-8 06 11.42	16.1	Europe, Africa, Asia, Atlantic
	1998								
C39	25 Jan	13:41	0.27n	22.6	59	16 28 04.590	-9 37 52.53	15.3	W. N.America
C41	27 Jun	4:17	0.82n	20.1	148	16 22 06.146	-9 01 55.79	15.7	S.America, E. N.America
C42[a]	9 Jul	21:58	0.97s	16.7	137	16 21 01.635	-9 03 30.47	14.7	Europe, Africa, E. S.America
C43[a]	7 Aug	12:25	0.67s	8.2	110	16 19 33.762	-9 12 05.77	15.7	W. Pacific
	1999								
C45[a]	1 Feb	18:45	0.05s	20.4	63	16 37 43.506	-10 29 39.10	14.7	Australia
C46[a]	27 Feb	23:36	0.82n	8.4	89	16 39 22.097	-10 25 27.11	15.1	India, Central Asia
C48[a]	11 Jul	22:53	0.28n	17.1	138	16 30 13.718	-9 58 51.54	15.6	Europe, Africa, S.America
C49[a]	26 Sep	0:51	0.04s	19.7	66	16 29 58.316	-10 32 05.73	12.7	S.America, E. N.America

[a] possible occultation by Pluto
[b] Extremely weak image with uncertain position.
[c] This is southwest component of close pair of equal brightness.

are from the Kron–Cousins system. All observations were obtained through a 14 arcsec aperture under dark and photometric skies. The standard stars used in the photometric reductions were taken from Landolt (1983). The photometry for the nine candidate stars is shown in Table 3. The fit to the standard stars was good to 0.02 mag in the U filter while the other filters were slightly better fit. Two of the objects were known beforehand to be slightly extended objects (galaxies). The surface brightnesses of the galaxies were sufficiently low that a positive identification in the TV finder was not possible and no useful photometry was obtained.

The infrared measurements, also shown in Table 3, were derived from images taken at UKIRT with IRCAM (a 58 by 62 pixel array, infrared imaging camera). The UKIRT staff provided data upon which a linearization correction was applied. This raw data was then corrected by subtracting a bias frame (zero-exposure frame from the camera), subtracting a dark frame (scaled to the same exposure time as the object image), dividing by a flatfield response image taken from the inside of the telescope dome, and subtracting a sky image from each object frame. The sky image used was taken immediately after each object frame at a position 60 arc-sec to the east of the object. Once each frame was calibrated in this manner, a total object flux was extracted from the image by summing the counts in a 6 pixel (3.6 arcsec) radius circle centered on the star and subtracting the background determined from an average of the counts in an annulus with inner and outer radii of 10 and 20 pixels (6.2 and 12.4 arcsec), respectively. The magnitudes listed in Table 3 should be good to 10%–15% where the uncertainty estimate is entirely due to systematic errors and is derived from past experience of the UKIRT staff in using IRCAM. The random errors in all measurements were less than 1% in all cases.

6. RECOMMENDATIONS

Because of the faintness of Pluto and Charon, the observation of the occultation of any of the stars within our measurement limits could provide good data if observed with a telescope of large enough aperture. All of these stars are so faint at visible wavelengths that useful observations can best be obtained using 1 m or larger telescopes.

There are three times when the same star may be occulted by both Pluto and Charon: 8 January 1995 (P/C24), 6 July 1995 (P/C28), and 26 September 1999 (P/C49). P/C24 may be occulted by both Pluto and Charon at some observatories (nominally in Europe). The 6 July 1995 event is most widely observable, the Pluto ground track being north of Charon's. With the nominal tracks over northern South America, a change in star position is likely to move the event toward more observatories. P/C49 is one of the brightest found in the search; it will cast Pluto's shadow less than one Earth diameter north of Charon's.

Among the Pluto events, good events include 1 March 1992 (P16), where a north–south occultation track could hit both Japan and New Zealand, 3 October 1993 (P20), visible in Australia, 17 April 1996 (P30), visible from the eastern U.S. and the Canary Islands, 9 July 1998 (P42), visible over Europe, Africa, and the Atlantic Ocean, and 27 February 1999 (P46), visible over India.

There are several good possibilities among the Charon events. On 20 June 1990 (C12), there is a promising occultation by Charon of a 15th magnitude star, with the nominal ground track across Cape York in Australia, crossing the Pacific near the equator. On 30 January 1992 (C15), Charon's nominal shadow hits the western U.S. The 28 July 1996 (C32) event with slight changes to the star's declination could hit either the east coast of the U.S. or South American observatories, and the 1 February 1999 (C45) event, with a slightly larger star position change, could touch Australia or Japan.

Finder charts for those stars considered to be the best occultation candidates in Tables 1 and 2, that is, those less than 0.5 arcsec from Pluto or Charon and observable from a large enough area to hit several telescopes, are provided in Fig. 1. Each finder chart is an extraction from the digital plate cata-

TABLE 3. Photometry of occultation candidate stars.

Pluto Number	Closest Approach Date	U.T.	Guide Star Region	Number	U	B	V	R	I	K
P/C10	1990 9 Jan	23:53	5006	309	13.83	13.78	13.13	12.72	12.32	11.4
galaxy	1990 26 Jan	13:20	5006	365	—	—	—	—	—	13.3
P/C12	1990 20 Jun	9:50	5001	764	15.56	15.70	15.13	14.78	14.43	13.4
galaxy	1991 16 Sep	13:58	5006	320	—	—	—	—	—	14.6
P/C17	1992 21 May	6:19	5020	294	14.26	14.16	13.47	13.03	12.59	11.6
P20	1993 3 Oct	9:16	5025	552	13.90	13.31	12.31	11.76	11.24	9.9
P/C24	1995 8 Jan	3:37	5044	934	15.90	15.37	14.41	13.88	13.31	12.0
P27	1995 14 Jun	14:36	5031	434	15.65	15.50	14.74	14.39	14.09	12.7
[a]	1995 6 Sep	6:00	5031	160	11.05	10.84	10.15	9.73	9.34	8.5

[a] Plate position missed Pluto by almost 2 arcsec, dropped from prediction table
α = 16 01 52.331, δ = -7d 37 44.39

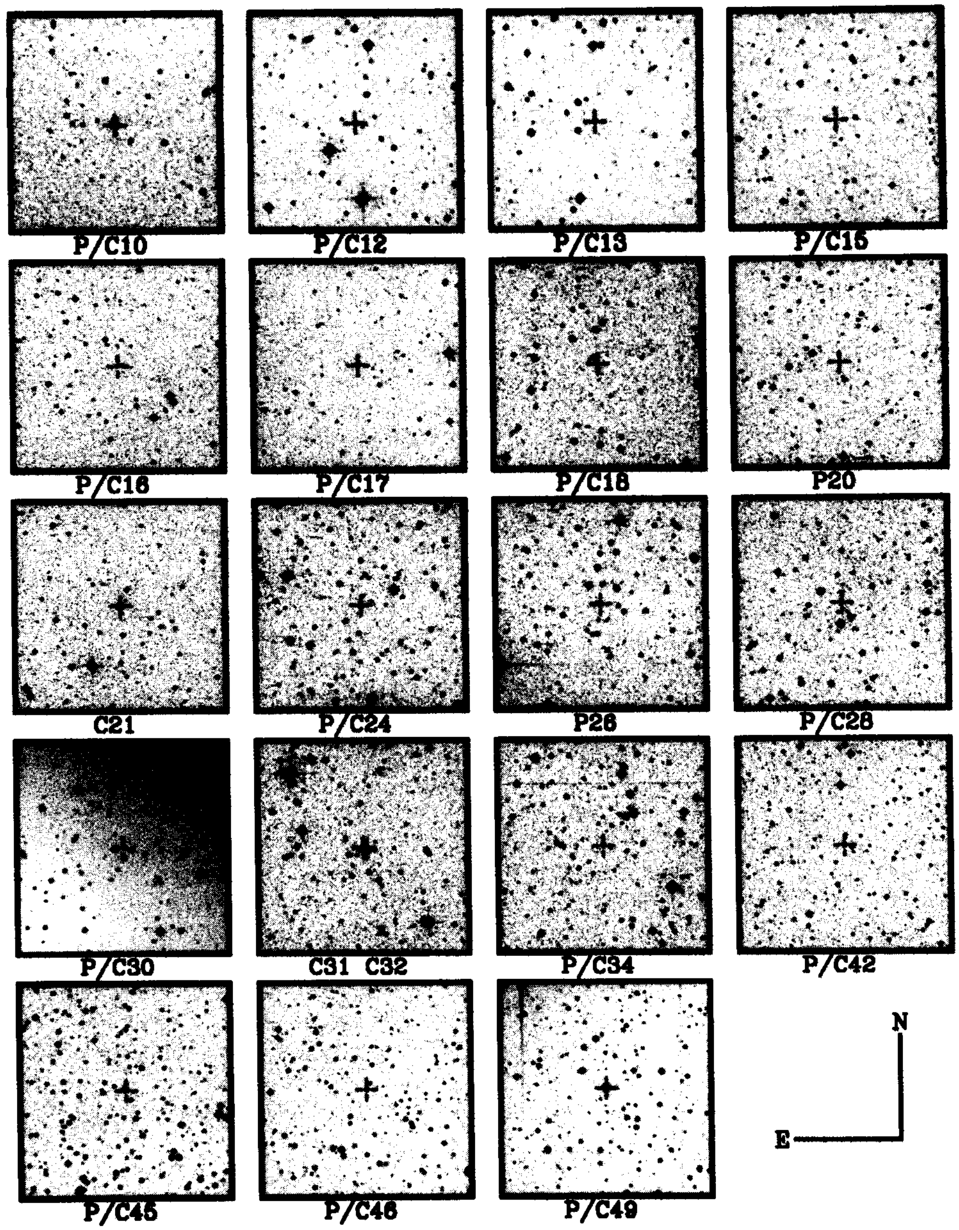

FIG. 1. Finder charts for some stars which may be occulted by Pluto and Charon. The numbers are the event numbers in Tables 1 and 2. Note that the star occulted by Charon in event C32 is on the lower right of the star labeled C31.

log at the Space Telescope Science Institute. In all cases the chart covers a 7 by 7 arcmin patch of sky. At the bottom of each chart is the star ID (P for Pluto events and C for Charon events). The extraction was centered at the position on the plate (in the *Guide Star Catalog* plate coordinate system) that corresponded to the coordinate for each star as shown in Tables 1 and 2. The hollow symbol in each chart was placed at the center of each image and shows the coordinate of each star according to the *Guide Star Catalog* plate solution. In most cases, the agreement is quite good. However, one of the stars does not closely fall in the predicted place according to the *Guide Star Catalog*. Close reexamination of the photographic plate measurements reported in this work, as well as the coordinates used to extract the portion of the *Guide Star Catalog* plate, did not reveal any errors. Therefore, we must conclude that there is a large (~ 3 arcsec) systematic error in the *Guide Star* plate coordinates for that star. Further photographic plates will be measured in the future to improve positions and predictions for the stars in Tables 1 and 2.

The work was supported in part by NASA Grant Nos. NAGW-1525 (A.R.K.) and NAGW-1490 (D.J.M.). D. Tholen assisted with the photometry. We thank E. M. Standish for improving the JPL Pluto ephemeris. M. Buie acknowledges the support of the United Kingdom Infrared

Telescope, which is operated by the Royal Observatory Edinburgh on behalf of the U. K. Science and Engineering Research Council. We also thank E. A. Harlan for observations with the Lick astrograph and B. Lasker and C. Sturch for providing a magnetic tape version of the *Guide Star Photometric Catalog*. E. W. Dunham and S. W. McDonald generously provided access to their CCD photometry and astrometry of the stars in our survey.

REFERENCES

Binzel, R. P., Tholen, D. J., Tedesco, E. F., Buratti, B. J., and Nelson, R. M. 1985, Sci, 228, 1193
Blow, G. L., and Priestley, J. 1988, IAU Circular No. 4611
Brosch, N., and Mendelson, H. 1985, IAU Circular No. 4097
Buie, M. W., and Tholen, D. J. 1989, Icarus, 77, 23
Dunham, E. W., McDonald, S. W., and Elliot, J. L. 1990, BAAS, 22, 1129
Elliot, J. L., and Dunham, E. W. 1988, IAU Circular No. 4611
Elliot, J. L., Dunham, E. W., Bosh, A. S., Slivan, S. M., Young, L. A., Wasserman, L. H., and Millis, R. L. 1989, Icarus 77, 148
Halliday, I. 1963, JRASC, 57, 163
Halliday, I. 1965, S&T, 29, 216
Halliday, I., Hardie, R. H., Franz, O. G., and Priser, J. B. 1966, PASP, 78, 113
Høg, E., and von der Heide, J. 1976, Abh. Hamburger Sternw., 9
Kilmartin, P. M., Allen, W. H., and Gilmore, A. C. 1988, IAU Circular No. 4612
Klemola, A. R., Jones, B. F., and Hanson, R. B. 1987, AJ, 94, 501
Landolt, A. U. 1983, AJ, 88, 439
Lasker, B. M., Sturch, C. R., Lopez, C., Mallama, A. D., McLaughlin, S. F., Russell, J. L., Wisniewski, W. Z., Gillespie, B. A., Jenkner, H., Siciliano, E. D., Kenny, D., Baumert, J. H., Goldberg, A. M., Henry, G. W., Kemper, E., and Siegel, M. J. 1988, ApJS, 68, 1
Lasker, B., Sturch, C., McLean, B. J., Russell, J. L., Jenkner, H., and Shara, M. M. 1989, AJ, 99, 2019
Marcialis, R. L. 1988, AJ, 95, 941
Mattram, K., Kennedy, H., Hickey, D., and Murphy, T. 1988, IAU Circular No. 4612
Millis, R. L. 1988, IAU Circular No. 4611
Millis, R. L., and Wasserman, L. H. 1983, IAU Circular No. 3780
Mink, D. J. and Buie, M. W. 1989, BAAS, 21, 1010
Mink, D. J., and Klemola, A. R. 1985, AJ, 90, 1894
Page, A. A., and Mitropoulos, P. 1988, IAU Circular No. 4612
Shelus, P. J., and Benedict, G. F. 1978, private communication
Standish, E. M. 1987, Jet Propulsion Laboratory Interoffice Memorandum IOM 314.6-891
Taylor, G. E. 1978, Working Group on the Prediction of Occultations by Satellites and Minor Planets (IAU Commission No. 20), Bull. No. 10
Taylor, G. E. 1984, Working Group on the Prediction of Occultations by Satellites and Minor Planets (IAU Commission No. 20), Bull. No. 32
Tholen, D. J., Buie, M. W., and Swift, C. E. 1987, AJ, 94, 1681
Tholen, D. J., and Buie, M. W. 1988, AJ, 96, 1977
Walker, A. R. 1980, MNRAS, 192, 47
Walker, W. S. G., Marino, B. F., Dix, D. G., and Urquhart, G. 1988a, IAU Circular No. 4612
Walker, W. S. G., Marino, B. F., Dix, D. G., and Urquhart, G. 1988b, IAU Circular No. 4620
Watson, R. D., Hill, K. M., and Dieters, S. W. 1988, IAU Circular No. 4612