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The 1977 Palomar-Leiden Trojan Survey

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Summary. The 1977 Trojan campaign, consisting of 68 plates taken in October 1977 with the 122 cm Schmidt telescope of Palomar Observatory, is reviewed here. The orbital elements derived from this material are published in the Minor Planet Circulars. The accuracy of the positions is derived, as well as the photometric accuracy. The density of field asteroids as a function of latitude is determined, up to a latitude of 15°, and it is found that this function is equal for bright and faint asteroids, within the accuracy limits of this investigation. In this program 26 Trojan asteroids were found, 5 Hungaria-type asteroids and only one Hilda-type asteroid. The accuracy of the orbital elements derived from a 15 or 14 days arc in the present survey turns out to be comparable to first-class orbits in the Palomar-Leiden Survey (PLS), and the orbits derived here from a 10 or 11 days arc are considerably better than the third class PLS orbits, which are based on a 9 days arc. It can be shown that the limiting magnitude of the asteroids found is practically the same for the PLS and the present survey; it follows that, down to photographic magnitude 20.0 (PLS) the number of Trojans found here is complete.

Key words: asteroids

1. Introduction

In 1970 a study was published (van Houten et al., 1970a) deriving the number of Trojans around the preceding Lagrangian point (L_4). Shortly after this publication appeared doubts arose whether the numbers of Trojans around the two libration points (L_4 and L_5) were equal. To settle this question three separate programs were started, in 1971, 1973 and 1977, in which the region of the libration points L_5, L_4 and again L_5 were observed, respectively. For practical purposes all these programs were limited to the centres of the Trojan regions. This is only justified if the spatial distribution of Trojans within these regions is equal. This is supposed here to be the case; verification of it would mean a considerable amount of observational work.

The 1977 survey is the first to be completed. It was decided to measure positions and magnitudes of all asteroids found, which was very time-consuming. The aim is to increase the supply of orbits of faint asteroids as given by the Palomar-Leiden survey (PLS, van Houten et al., 1970b).

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Table 1. Plate centres of the fields photographed in this survey

No.	α (1950)			δ (1950)	
(1)	0ʰ	54ᵐ	6ˢ	+17°	27′.4
(2)	1	4	35	+11	48.2
(3)	1	14	19	+ 6	32.9
(4)	1	23	42	+ 0	59.8
(5)	1	32	9	− 4	50.4

The present survey consists of five fields, with 13 plates each (12 for the most southern field), and four plates centered on Selected Area 68, taken for photometric calibration. The plate centres of the five survey fields are given in Table 1. The five fields together form a strip, centered on and perpendicular to the ecliptic. The purpose of this arrangement is to determine the apparent concentration of field asteroids toward the ecliptic, extending to a latitude of about 15°.

The plates were taken on 1977 October 7, 11, 12, 16, 17, 21 and 22 with the 122 cm Schmidt telescope of Palomar Observatory by T. Gehrels. They were taken in pairs, to be used in a blink microscope; the time interval between two plates of a pair is about two hours. Only in the first night single plates were taken on account of clouds. The telescope was guided on mean Trojan motion. The size of the fields is approximately 6°.5 × 6°.5. The centres given in Table 1 refer to the central dates (October 11, 12, 16, 17); for the other dates the centres were shifted to follow the mean Trojan motion.

The further division of labour was as follows: I. van Houten-Groeneveld took care of the blinking of the plates and the positional measurements, M. Wisse-Schouten did the photometry and C. Bardwell computed the orbital elements. C.J. van Houten discussed the material.

2. Positions and orbital elements

Positions were measured with the blink microscope of the Catholic University at Nijmegen, which instrument can be used both for blinking and for positional measurements. The accuracy of these positions was derived from the residuals of 35 well-determined orbits, divided equally over the different magnitude intervals. No

Table 2. T-3 numbers for identifications with preliminarily designated asteroids

T-3	Preliminary designation	T-3	Preliminary designation
1002	1982 BG_1	3392	1977 RJ_6
2002	1977 RP_7	3416	1980 FG_{12}
2116	1977 RY_6	4277	1977 VL_1
2176	1977 RD_7	4279	1977 UD
2209	1977 RB_7	4337	1977 SD_3
3146	1969 TE_2	5091	1977 TO_6
3162	1977 RL_7	5093	1977 SS_2
3213	1977 RR_7	5147	1977 TQ_6
3281	1977 RO_7	5150	1977 SG_3
3363	1977 TG_7	5169	1984 EZ

dependence of accuracy on magnitude was found. The average residual was 0''.75 in each coordinate, yielding an internal error of 1''.05 per position.

Orbital elements could be derived for 1491 asteroids. The complete set of orbital elements is published in Minor Planet Circulars (MPC) 12536–12560, dated 1987, December 5. The elements of those asteroids that were identified with already numbered asteroids are not in this listing. Part of the asteroids identified with known asteroids with a preliminary designation were combined with the latter and orbital elements are given for the combined material in the MPC's; they are denoted there with their provisional designation. A list of these objects, together with their T-3 number, is given in Table 2. In view of the sparsity of earlier observations the majority of these objects must be regarded as T-3 discoveries, although they have no T-3 number in the MPC's.

3. Accuracy of orbit computation

Several of the asteroids found could be identified with numbered or preliminarily designated asteroids. Their orbits as determined in this program were compared with those published in the 1988 ephemeris (the numbered objects) and with orbits published in the Minor Planet Circulars (preliminarily designated asteroids). In total forty such comparisons could be made. The differences obtained were compared with the corresponding values found in the PLS; the absolute values of these differences are denoted residuals in the discussion below.

The PLS material is divided into four quality classes, with respect to the bright-of-the-moon gap in the observations. A similar division can be made in the present material, depending on the arc length (arcs of 15 or 14 d, of 10 or 11 d and of 5 or 6 d). These comparisons are shown in Table 3. The PLS residuals of first-class orbits were recomputed, since after the publication of the PLS many more PLS first-class objects were definitely numbered, and thus the residuals are much better determined. The present determination is based on 86 asteroids.

Inspection of Table 3 shows that the PLS residuals are rather similar for the first-class PLS orbits and those based on the 15 or 14 d arc in the present material. Apparently the more regular distribution of positions along the arc in the 1977 material largely compensates for the larger arc and the better positional accuracy of the PLS material. One exception must be made, however: the orbital inclination is better defined in the PLS than in the present program; relative to the other residuals those of the 1977 inclinations are four times as large as those of the PLS.

The 1977 orbits based on a 10 or 11 d arc are compared with the third-class orbits of the PLS, which have an arc of nine days length. In spite of the similarity of the arc length the 1977 orbits turn out to be considerably better, their residuals being only one-third of the corresponding values of the PLS orbits. Again excepting the inclination: here again, relative to the other residuals, the residuals of the inclination turn out four times as large in the present material compared to the PLS. The cause of this difference is not clear.

Lack of suitable comparison material prevented us to determine the accuracy of the orbits based on the 5–6 d arc.

4. Photometry

Photometric magnitudes were obtained by means of the Sartorius iris photometer of the Leiden Observatory, using Selected Area 68 as a photometric standard. This is the same standard as used in the PLS, so that the two sets of magnitudes should be directly comparable. The magnitudes were corrected for trail effects, for which the relation between magnitude correction and trail length as found for the PLS material was used. The 1977 plates were rather fogged, so that calibration difficulties can be expected when field plates and calibration plates have different fog level. In practice it turned out that such errors were small close to the plate limit and increased with increasing apparent brightness. In total up to four magnitude determinations of each asteroid were made.

An impression of the accuracy of the photometry can be obtained by comparing absolute magnitudes from the present material with reliable determinations published elsewhere. Conversion terms for obtaining the new absolute magnitude H (see

Table 3. Average differences without regard to sign between PLS or T-3 orbital elements and standard elements. The numbers in parentheses denote the number of orbits used in the comparison

Element	PLS 1st class	T-3 15–14 d arc	PLS 3rd class	T-3 11–10 d arc	Unit
a	0.0044 (86)	0.0058 (40)	0.0320 (543)	0.0073 (10)	AE
e	0.0034	0.0057	0.0310	0.0083	
i	0.028	0.14	0.170	0.25	Degree
Ω	0.34	0.34	0.70	0.51	Degree
ω	2.1	3.0	19.2	4.3	Degree

Table 4. Comparison between absolute magnitudes derived in this program and catalogued values

No.	1977	Catalogue	Source	Difference
(93)	9.31	8.55	MD	+0.76
(327)	11.12	11.30	MD	−0.18
(758)	9.38	9.17	p.e.	+0.21
(823)	12.04	12.51	MD	−0.47
(1186)	10.56	10.25	p.e.	+0.31
(1309)	11.55	11.30	MD	+0.25
(2041)	13.23	13.64	PL	−0.41
2121 P-L	16.82	16.98	PL	−0.16
2208 P-L	17.12	17.18	PL	−0.06
2570 P-L	14.32	14.12	PL	+0.20
2574 P-L	14.68	14.66	PL	+0.02
4127 P-L	15.33	15.77	PL	−0.44
4192 P-L	14.80	14.89	PL	−0.09
4831 P-L	15.50	15.94	PL	−0.44
6245 P-L	15.76	15.78	PL	−0.02
6573 P-L	14.50	14.58	PL	−0.08
6608 P-L	17.17	17.18	PL	−0.01
6766 P-L	13.26	13.48	PL	−0.22
6829 P-L	14.16	14.14	PL	+0.02

Source: MD = Kuiper et al. (1958); p.e. = Bowell, Gehrels and Zellner (1979); PL = van Houten et al. (1970b)

Table 5. The number of asteroids found in this program as a function of latitude and brightness

Field no.	Latitude	Asteroids found	
		all	$m < 18.00$
1	+10°.7	196	27
2	+ 4.6	343	54
3	− 1.2	438	63
4	− 7.2	330	49
5	−13.4	173	25

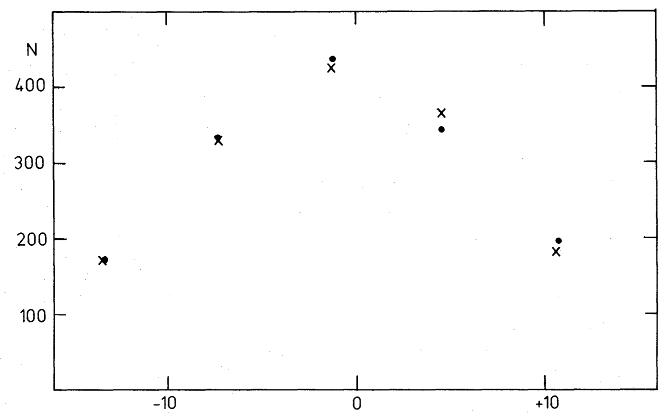

Fig. 1. Numbers of asteroids found per field, as a function of latitude. Dots: all asteroids found: crosses: 6.8 times the number of asteroids brighter than 18.00 mag

MPC 10193) from the present material were computed by C. Bardwell; he adopted a value of 0.25 for the parameter G characterizing the phase function. They were converted to old-style photographic absolute magnitudes by adding 0.80 mag for the colour difference and an estimated 0.36 mag for the phase function zero-point difference. Nineteen asteroids could be found for such a comparison: they are collected in Table 4. It is seen that some of the differences are considerable, but no systematic difference is apparent: the mean difference is -0.04 mag ± 0.07 (m.e.). However, if the comparison is limited to the PLS (13 objects), an average difference of -0.19 mag ± 0.05 (m.e.) is found, which is probably significant. Part of the difference may be caused by an incorrect transformation from new to old absolute magnitudes. The standard deviation of all comparisons is 0.31 mag and for the comparisons with the PLS 0.20 mag.

The accuracy of the PLS magnitudes is given by van Houten et al. (1970b) as 0.12 mag. In combination with the accuracy of the differences, 0.20 mag as found above, the accuracy for the present absolute magnitudes turns out to be 0.16 mag. In this number are included errors introduced by errors in the orbital elements, and by aspect variations. The effect of errors in the semi-major axis can be calculated easily; they turn out to be, on the average, 0.010–0.015 mag for an arc length of 10 to 15 d. If the contribution of errors in the other orbital elements is of the same order of magnitude, then they are negligible compared to the photometric errors.

5. Concentration of asteroids towards the ecliptic

Table 5 shows the number of asteroids per field, which yielded an orbit, and the latitude of the fields. Overlaps have been avoided here; the asteroids found in overlapping regions have been counted in the field to the north of the overlap. This means that, in order to obtain the true number of asteroids discovered in each field, all numbers given in Table 5 have to be increased by an estimated 3%, except for the most northern field. The numbers given in Table 5 are shown graphically in Fig. 1. It is seen that the distribution is symmetrical with respect to $b = -1°$ (the orbit of Jupiter) and that at 10° distance from this centre the density has decreased to 54% of its central value.

Table 5 also gives the corresponding numbers of asteroids with apparent magnitudes brighter than 18.00 (photometry of this paper). These numbers, multiplied by 6.8 to make the total of these objects equal to the complete material, are denoted by crosses in Fig. 1. It is clear that here the distribution in latitude of the brighter objects is not different from the fainter asteroids, within the limit of accuracy of the present material. This is at variance with a result by Mikami and Ishida (1987) who claim to have found that brighter asteroids are less concentrated towards the ecliptic than fainter ones. The present investigation is rather limited, however, both regarding magnitude and latitude range. This matter should be investigated more fully.

6. Incompleteness of the Trojan counts

The PLS determined the completeness of the number of asteroids found, down to a fixed level of magnitude, by comparing the number of discoveries of the same objects on the different dates on the same field. Since in the present program two plate pairs per field were blinked, the same approach can be made here.

We are interested in the number of Trojans with opposition magnitudes brighter than photographic magnitude 20.0. Taking into account the systematic difference between the PLS magnitudes and the present survey, we shall adopt the PLS zero point and look for all Trojans found in this program with a magnitude brighter than 19.81. We are only interested in the magnitude interval 19.31–19.81, all brighter intervals can be regarded as complete. In this interval 10 Trojans were found, 9 of them twice, 1 once.

If, in accordance with the PLS, N_2 is the number of Trojans found twice during blinking, N_1 the number found once and N_0 the number found not at all, then

$$N_2/N_1 = k^2/2k(1-k) \text{ and } N_0 = N(1-k)^2 ;$$

$N = N_1 + N_2 + N_0$ and k is the discovery probability. Taking $N_2 = 9$ and $N_1 = 1$, we find $N_0 = 0.03$. The material is thus complete, down to PLS magnitude 20.0. The total number of Trojans found in this program brighter than this limit equals 21.

A more indirect way of determining the completeness of the Trojan discoveries is to compare the number of asteroids found in the present program with the PLS material.

This comparison shows that the number of orbits obtained from one field is very similar in the two programs, if differences due to the positions on the sky (relative to the ecliptic) and to the date of exposure (with respect to the opposition date) are taken into account. This implies that the effective plate limit in both programs is practically the same. Therefore, the degree of completeness for asteroids brighter than 20.0 as found in the PLS also applies to the present material. The PLS degree of completeness for this limit is 0.99 (1% incomplete), which again yields the result that no Trojans brighter than this limit were missed during the present survey.

7. Conclusion

In total 1491 asteroids were found in this program for which orbital elements could be obtained. Of these, 32 are already definitely numbered and 31 have a preliminary designation. The number of Trojans found is 28 (two of these were already known), 5 are Hungaria-type asteroids. Only one Hilda-type asteroid was found, which is surprisingly low as compared with the PLS. The Trojan statistics will be discussed in a later paper, together with the results of the 1971 and 1973 programs.

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