NAGW-232

THE DISCOVERY CIRCUMSTANCES OF EARTH-APPROACHING ASTEROIDS

(NASA-CR-174327) THE DISCOVERY CIRCUMSTANCES OF EARTH-APPROACHING ASTEROIDS (Lincoln Lab.) 34 p HC A03/MF A01 CSCL 03B

N85-17920

Unclas

G3/91 17347

L. G. Taff

Patrice M. S. Randall

Lincoln Laboratory, Massachusetts Institute of Technology

Lexington, Massachusetts 02173

Number of Pages: 25

Number of Figures: 6

Number of Tables: 3

The U.S. Government assumes no responsibility for the information presented.

Running Head: Asteroid discoveries

Proofs etc. to: Dr. L. G. Taff

L-125

Lincoln Laboratory, MIT

P.O. Box 73

Lexington, MA 02173

Abstract

We have analyzed the discovery circumstances of all Earth-approaching asteroids detected in the last twenty-four years. In particular, we have calculated topocentric angular velocities, opposition distance, geocentric and heliocentric distances, phase angle, and lunar phase at discovery in an effort to separate any selection effects between chance and purposeful (i.e., as the result of a systematic search) discoveries. Another motivation was the possibility of discerning useful clues how to search more efficiently for such objects. There are 60 minor planets in our sample. Our principal result is that the discovery of Earth-approaching asteroids is dominated by serendipity. Therefore, searching for them at the current relatively bright limits at less than a very high rate seems pointless.

I. FORMULATION

In this paper any asteroid whose perihelion distance is less than that of Mars's is termed an Earth-approaching object. This includes the Aten, Apollo, and Amor classes and a few Mars-crossing minor planets too. We have investigated the discovery circumstances of such objects with the intent of correcting the existing searches for systematic effects or exploiting such effects (if they exist) in order to enhance future search efforts. Because of the random first appearance on the celestial sphere of this usually fast-moving subset of the minor planets, any systematic advantage would be of great assistance. We looked for correlations amongst the discovery geocentric distance, heliocentric distance, phase angle, topocentric angular velocity, angular distance from opposition, lunar phase at the time of discovery, and seasonality variations of discovery rates.

In order to compute much of this information one needs an orbital element set. Orbital element sets for this subset of asteroids vary widely in quality. Factors influencing the accuracy of the element set include the total observational arc (days, months, or years herein), the distribution of astrometric data over this time span, the recovery of "pre-discovery" observations (again days to years for some members of this group), and the quality of the individual observations themselves. For some objects several element sets are now available and represent various stages in the differential correction process. It was impossible to choose element sets of uniform quality. Given our desire to perform the essential research of this paper, some compromise had to be reached. The detailed references to the particular element sets we employed are given in Table I.

The longest running Earth-approaching asteroid search is that of Helin and Shoemaker, 1979. It dates from 1973. (Our own search is only four years old; Taff, 1981.) We have used the last eleven years and the preceding eleven too as the base for our sample. This includes 60 minor planets. Our aim in this case was to try and balance, as much as possible, the pre-search era with the post-search era. In this way we hoped to minimize long term effects having to do with the weather, observatory existence, distribution, and equipment, the essential observing techniques, and even astronomical fashion. Bringing the study up to date, (e.g. 1983VA, and so on) would only increase the number of objects without good element sets. Backdating further, say to include the Palomar-Leiden survey would add 1960VA = 2061, 1959EH = 1980RB1 = 2629, 1959LM, and three P-L objects (4789, 6344, 6743) for which the discovery circumstances were not published. Again we have made a debatable choice.

The original pair of discovery observations and orbital element sets have been taken directlv from the appropriate Minor Planet Circulars or International Astronomical Union Circulars.

The catalogues of Marsden and Bardwell, 1982a, b, proved very helpful in this regard as did a complete list of Atens, Apollos, and Amors kindly supplied to us by Dr. E. F. Helin.

In the next section we discuss the calculation of our derived quantities and in the following one we analyze it in several wavs. Our conclusions are in the last Section.

II. DATA CONSTRUCTION

a) Angular Velocities

Ideally the minor planet left a long trail, on a well timed plate, so that both ends of the trail could be independently measured and reduced. Slightly less ideal are two different photographs from the same night. In a few cases days intervened between the initial pair of observations. In even fewer instances there was only a single data point. Except in the last instance or when the textual remarks in an IAU Circular provided detailed information, we calculated $\Delta\alpha$, $\Delta\delta$, and Δt in the obvious way. The topocentric angular speed ω and position angle P were then computed from

$$(\Delta\alpha/\Delta t)\cos\ \delta = \omega \sin P$$

$$\Delta\delta/\Delta t = \omega \cos P$$

ω is given in degrees/day (to the nearest hundredth) and P is given in degrees (to the nearest one) in Table I [columns 4 and 5; column 2 gives the original source of the data (MPC or IAUC) and column 1 gives the provisional designation]. Those values computed from the longer time spans or other less reliable means are indicated by a colon in Table I.

b) Opposition Distance and Phase Angle

We used the geocentric (solar system barycentric post-1980) equatorial rectangular coordinates of the Sun (Earth) to compute the solar right ascension and declination at the discovery time. Then we coupled this linearly interpolated information from The American Ephemeris and Astronomical Almanac (The Astronomical Almanac) with the discovery location to compute the angular distance from the opposition at the instant of discovery. This is listed in the tenth column of Table I. The discovery location came from the element sets whose MPC source is given in the third column of Table I. We assumed that there were no perturbing influences acting over the time spans involved and that the element sets were representative of an osculating heliocentric location and velocity.

Phase angles were calculated from the above information according to their definition. They are listed in the ninth column of Table I. The heliocentric (r) and geocentric (R) discovery distances occupy columns seven and eight of the Table.

c) Lunar Phase and Seasonality

We anticipated that most discoveries would occur near New Moon rather than near Full Moon. We assigned Full Moon a phase of 0, First Quarter a phase of 0.25, New Moon a phase of 0.5, and Third Quarter a phase of 0.75. From the discovery date, the lunar synodic period, and old issues of The American Ephemeris and Nautical Almanac (or The Astronomical Almanac post-1980) the phases in the sixth column of Table I were deduced. Another thing we examined was the seasonality variation -- both monthly and in seasons. As almost all of this information is present in the provisional designation, we have not listed the actual discovery dates.

Table I. Data on Earth-approaching Asteroids

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1963UA	2308	3016	0.89:[b]	136:[b]	0.44	1.25	0.25	2.5	3.1
1968AA	2845	3017	0.39:	324:	0.51	1.48	0.71	34.6	58.7
1971FA	3895	3754	0.64	274	0.48	1.86	0.86	0.7	1.4
1971SC	3299	5032	0.51	165	0.75	1.37	0.37	7.7	10.5
1971UA	3896	3755	1.08	223	0.76	1.36	0.37	1.9	2.5
1972RA	3381	4659	0.77:	130:	0.46	1.23	0.22	4.6	5.6
1972RB	3381	4659	1.23	108	0.76	1.14	0.13	4.7	5.3
1972XA	3618	3756	1.44	324	0.50	1.18	0.23	29.8	36.5
1973EA	3525	4010	1.20	282	0.57	1.29	0.41	36.1	50.1
1973EC	3525	3899	0.80:	150:	0.80	1.14	0.23	47.2	57.0
1973NA	3601	4659	11.90	206	0.62	1.11	0.09	14.6	16.0
1974MA	3712	4659	0.91	31	0.73	1.40	0.68	43.4	70.5
1974UB	3813	3910	0.88:	304:	0.67	1.68	0.69	5.7	9.5
1975TB	5393	4541	2.43	210	0.40	1.13	0.16	32.9	37.9

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Desig- nation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1975YA	3918	3919	20.32	337	0.29	1.02	0.05	40.2	42.0
1976AA	3918	3919	2.51	328	0.67	1.11	0.13	7.1	8.0
1976UA	4395	4659	15.17	151	0.48	1.01	0.01	39.7	40.2
1976WA	4147	4660	0.58	14	0.41	1.36	0.61	41.8	66.3
1977HA	4193	4660	0.62	103	0.45	1.13	0.17	40.1	46.4
1977HB	4193	4406	1.24	256	0.68	1.19	0.18	1.5	1.8
1977RA	4392	4660	0.23:	39:	0.24	1.24	0.25	17.8	22.2
1977VA	4396	4660	0.83:	100:	0.42	1.13	0.14	5.0	5.7
1978CA	4392	4660	0.60:	352:	0.51	1.20	0.28	36.2	45.9
1978DA	4392	6827	0.77:	79:	0.81	1.20	0.24	25.3	31.2
1978RA	4496	4541	1.96	218	0.78	1.19	0.19	5.2	6.2
1978SB	4569	4661	1.29:	289:	0.38	1.32	0.33	15.3	20.3
1978VB2	4724	—	—	—	0.53	—	—	—	—
1979QA	4904	—	1.59:	280:	0.48	—	—	—	—

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Desig- nation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1979QB	4904	5515	0.17	354	0.48	1.34	0.33	4.2	5.6
1979VA	5120	5319	1.76	93	0.37	1.12	0.15	22.4	25.7
1979XA	5121	5176	1.32	257	0.32	1.24	0.31	29.6	38.6
1979XB	5120	5131	3.87	235	0.26	1.03	0.09	49.8	53.7
1980AA	5138	5279	2.58:	120:	0.39	1.05	0.07	12.2	13.1
1980PA	5514	5899	0.83	53	0.32	1.27	0.31	32.1	41.6
1980RB1	5594	5847	0.60	292	0.63	1.64	0.54	6.4	10.4
1980WF	5669	5841	1.07	136	0.24	1.13	0.14	7.7	8.8
1980YS	5827	5899	0.11	1	0.29	1.23	0.26	7.7	9.7
1981CW	5886	5977	0.67	64	0.57	1.19	0.30	42.2	53.9
1981ET3	7093	7234	0.34	267	0.39	2.50	1.56	9.4	24.4
1981JD	6036	---	3.14	240	0.68	—	—	—	—
1981QA	6237	6702	0.91	127	0.21	1.19	0.20	26.3	31.4
1981QB	6254	6702	1.48	192	0.43	1.40	0.40	8.4	11.8

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1981VA	6481	6702	2.19	196	0.74	1.22	0.29	32.5	41.5
1982BB	6674	6703	0.75	342	0.35	1.40	0.50	27.5	41.1
1982CA	6769	—	1.88:	248:	0.17	—	—	—	—
1982DB	6675	6831	0.74	282	0.68	1.06	0.11	47.7	52.3
1982DV	6690	6831	0.73	128	0.67	1.20	0.26	31.6	39.5
1982EA	6770	—	0.65	266	0.78	—	—	—	—
1982FT	6877	8538	1.07	211	0.66	1.31	0.36	26.3	35.5
1982HR	3692[a]	7840	2.49:	264:	0.54	1.05	0.06	38.4	40.4
1982RA	7202	7602	1.70	334	0.33	1.24	0.32	37.4	48.5
1982RB	3725[a]	7602	1.05	168	0.36	1.33	0.34	15.6	20.8
1982TA	7342	8539	0.93	263	0.27	1.48	0.50	13.8	20.6
1982XB	7563	7841	3.01	31	0.45	1.02	0.05	33.7	35.2
1982YA	3758[a]	8534	2.61:	190:	0.71	1.22	0.24	2.6	3.2
1983LB	8014	8056	1.48	205	0.59	1.31	0.30	10.4	13.5

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentric Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1983LC	8014	8056	0.80	295	0.59	1.23	0.23	13.4	16.4
1983RB	8119	8394	1.30	160	0.49	1.29	0.30	12.2	15.7
1983RD	3862[a]	8534	2.90	113	0.50	1.10	0.10	21.8	23.9
1983TB	8192	8278	3.09	93	0.64	1.03	0.38	74.6	96.0

[a] References marked by this symbol refer to an I.A.U. Circular. All others are MPC numbers.

[b] Colons indicate less certain values.

III. DATA ANALYSIS

a) Angular Velocities

We examined the angular velocity in three fashions. First we created the (binned) frequency of angular speeds, see Fig. 1. A bin size of $0\overset{\circ}{.}25$/d was used (e.g., $0^\circ/d \le \omega$ $0\overset{\circ}{.}25$/d and so forth) up to $3\overset{\circ}{.}25$/d. There were 4 minor planets with higher angular speeds. The average value of ω over the sample is $2\overset{\circ}{.}05$/d with a standard deviation about the mean (including Sheppard's corrections) of $3\overset{\circ}{.}38$/d. The lack of low speed Earth-approaching minor planets needs no explanation because topocentric angular speed is the principal method of discrimination for these objects. We have no deep insight into the form of the curve. Next we looked at the distribution of the position angles (Fig. 2). As you can see it is almost uniform except for a slight northeast quadrant deficiency. The mean position angle is 196° and the standard deviation about the mean (including Sheppard's corrections for the 45° size bins) is 95°. The northeast quadrant deficiency is especially evident when quadrant binning is used. The frequency distribution is now 8, 17, 18, 16 around the compass. Furthermore, there is no correlation between P and discovery date. Lastly we plotted, on polar coordinate graph paper, an angular velocity scatter diagram. The most striking feature about it is that there are no striking features.

b) Opposition Distance and Phase Angle

Let $\underline{r}_A$ be the heliocentric location of the asteroid, $\underline{r}_E$ the heliocentric location of the Earth, and $\underline{R}_A$ be the geocentric (≈ topocentric) location of the asteroid. Then the phase angle ϕ and the opposition distance Φ given by

$$\cos \phi = \frac{\underline{R}_A \cdot \underline{r}_A}{R_A r_A}, \qquad \cos \Phi = \frac{\underline{R}_A \cdot \underline{r}_E}{R_A r_E}$$

Since $\underline{r}_A = \underline{R}_A + \underline{r}_E$ and R_A is usually much smaller than r_E or r_A, it follows that

$$\cos \phi \approx \cos \Phi + (R_A/r_E) \cdot \sin \Phi$$

Hence, for most discoveries near opposition $\phi < \Phi$. Although there is a strong opposition effect (≈ $0\overset{m}{.}4$) in minor planet phase functions and an additional linear decrease of the phase function in magnitudes with increasing phase angle (beyond ≈ 8°), the histogram in Fig. 3 does not support the hypothesis that Earth-approaching asteroids are preferentially discovered near opposition. An equal area plot on the celestial sphere centered at opposition reinforces this conclusion. The phase angle at discovery frequency distribution is shown as the dotted histogram in Fig. 3. Apparently once an Earth-approaching minor planet becomes bright enough, and most are found with $V < 15^m$, it is detected by whomever photographed it and knew what to look for.

The geocentric and heliocentric distances in Table I show that Earth-approaching asteroids tend to be found when they approach the Earth. We assume that this is a consequence of their increased brightness and angular speed. There are unusual cases though (e.g., 1981ET3). The distributions are shown in Figs. 4 and 5.

c) Lunar Phase and Seasonality

We'll discuss seasonality first; the counts are given in Table II. There is a noticeable lack of non-uniformity due to a pronounced deficiency of discoveries during April, May, June, and July. We feel that the obvious Northern hemisphere bias of observatory distribution coupled with some elementary solar system geometry accounts for this (e.g., opposition is low in the sky at the summer solstice and the galactic plane high). Not surprisingly Spring is the lowest return season too: Winter 17, Spring 8, Summer 16, and Fall 19. The big jump in the number of September discoveries (which props up the Summer discovery counts) is probably a result of the geometrical factors mentioned above as well as observer bias due to the Spring drought, the short Summer nights, a few months rest, renewed enthusiasm, good Fall weather, and so on.

The distribution of lunar phases is shown in Fig. 6. As we anticipated there is a dearth of discoveries near Full Moon and a maximum near New Moon. There is no bias towards the waning

Table II. Monthly Discovery Variation

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Number	4	6	6	3	1	3	1	5	11	7	6	7

Third Quarter Moon relative to the waxing First Quarter Moon which is significant. Such an effect might have been predicted on the grounds that a well planned search would commence during the waning Third Quarter phase. For then, should an interesting asteroid be found, the maximum amount of dark time would be available for further observations. Alternatively, one's enthusiasm might be higher at the beginning of a search period then at the end, it is easier to work in the evenings than it is in the mornings, and one's eagerness and alertness would be expected to drop immediately after a discovery because experience has taught us of the rareness of any find.

d) Discovery Circumstances

What scientific research were the majority of the discoverers conducting when they exposed the photographic plate on which the minor planet's trail appeared? Most of them were not searching for Earth-approaching asteroids but were engaged in some other type of astronomy. In addition, some of the asteroids of interest credited to the Helin and Shoemaker, 1979 search were found while they were pursuing other studies. As an example 1981VA was found during a search for high inclination asteroids (Helin, et al., 1982). As a second illustration 1982DB was found while they were engaged in cometary studies. (JPL press relese #990 4/7/82 MBM; see also Aviation Week & Space Technology for May 10, 1982, pg. 51 or Sky and Telescope

63, 455, 1982.) These can clearly not be credited to their systematic Earth-approaching asteroid search efforts. As a third example we have 1981ET3, a "UCAS" discovery of R. Bus. In an effort to ascertain what fraction of the Earth-approaching asteroids discovered by and credited to the Helin and Shoemaker systematic search but should not be so attributed, we have critically examined their less well publicized discoveries.

IV. SEARCH STRATEGY AND PAYOFF

What do we know about the probability of occurrence, based on the 55 element sets referenced in Table I, of an asteroid of this type? The means and standard deviations about the means are shown in Table III. Clearly these object can come from most quarters of the celestial sphere but retrograde motion is ruled out (so far). Their speeds of approach (or recession!) are highly variable, no season or lunar phase is preferred, and so forth. The only certainty we have apart from this randomness is that they will be especially bright near opposition. The optimal search strategy for this situation is intuitively obvious and rigorous calculations (Taff, 1984) verify that it can be improved upon by less than 10%. Part and parcel of an efficient use of telescope time, photographic plates, human enthusiasm and fortitude, and so on is to search when the other constraints on the problem do not interfere. Thus, one should search near each New Moon and not in the Summer. June 23 and September 23 are equally unfavorable times of year except for a weather differential. Certainly Full Moons, July 15, and September 1 are to be avoided.

When are these minor planets actually found? Sixteen were found during the Summer (effectively one-quarter of the total of 60). Twenty-five were found outside of the optimum lunar phase range of (0.33, 0.67). While this is a lot closer to 1/3 of the

Table III. Orbital Element Statistics

Element	Mean	Standard Deviation
Semi-major axis	1.90 A.U.	0.55 A.U.
Eccentricity	0.489	0.163
Argument of perihelion	168°	101°
Inclination	17°.7	14°.8
Longitude of the Node	184°	96°

total than it is to 2/3 of it, seven of these were Summer events! Thus, thirty-four of sixty asteroids were found at most improbable times. Because we already know of the accidental discovery of at least three others (e.g., 1981ET3, 1981VA, and 1982DB), it becomes increasingly clear that careful planning and the husbanding of resources have little to do with the discovery of these objects. Serendipity rules the skies.

We conclude that purposeful organized searches with current techniques (e.g., specifically with respect to search rates and limiting magnitude) have not had and will not have a high payoff in terms of discoveries. Sky coverage, awareness of the quarry, and very hard work will continue to yield unpredictably large numbers of discoveries if additional objects remain to be found.

Acknowledgements

We wish to thank V. Alexander Nedzel for encouraging asteroid research at Lincoln Laboratory, Lynne M. Perry for her typing skills, the hospitality of the Harvard College Observatory and Smithsonian Astrophysical Observatory Libraries, and especially NASA for supporting this research (NAGW-232).

Figure Captions

Fig. 1. Histogram of the number of Earth-approaching asteroids as a function of topocentric angular speed at time of discovery.

Fig. 2. Same format as Fig. 1 for position angle of topocentric angular velocity.

Fig. 3. Same format as Fig. 1 for opposition distance.

Fig. 4. Same format as Fig. 1 for geocentric distance at time of discovery.

Fig. 5. Same format as Fig. 1 for heliocentric distance at time of discovery.

Fig. 6. Same format as Fig. 1 for lunar phase (New Moon = 0.5) at time of discovery.

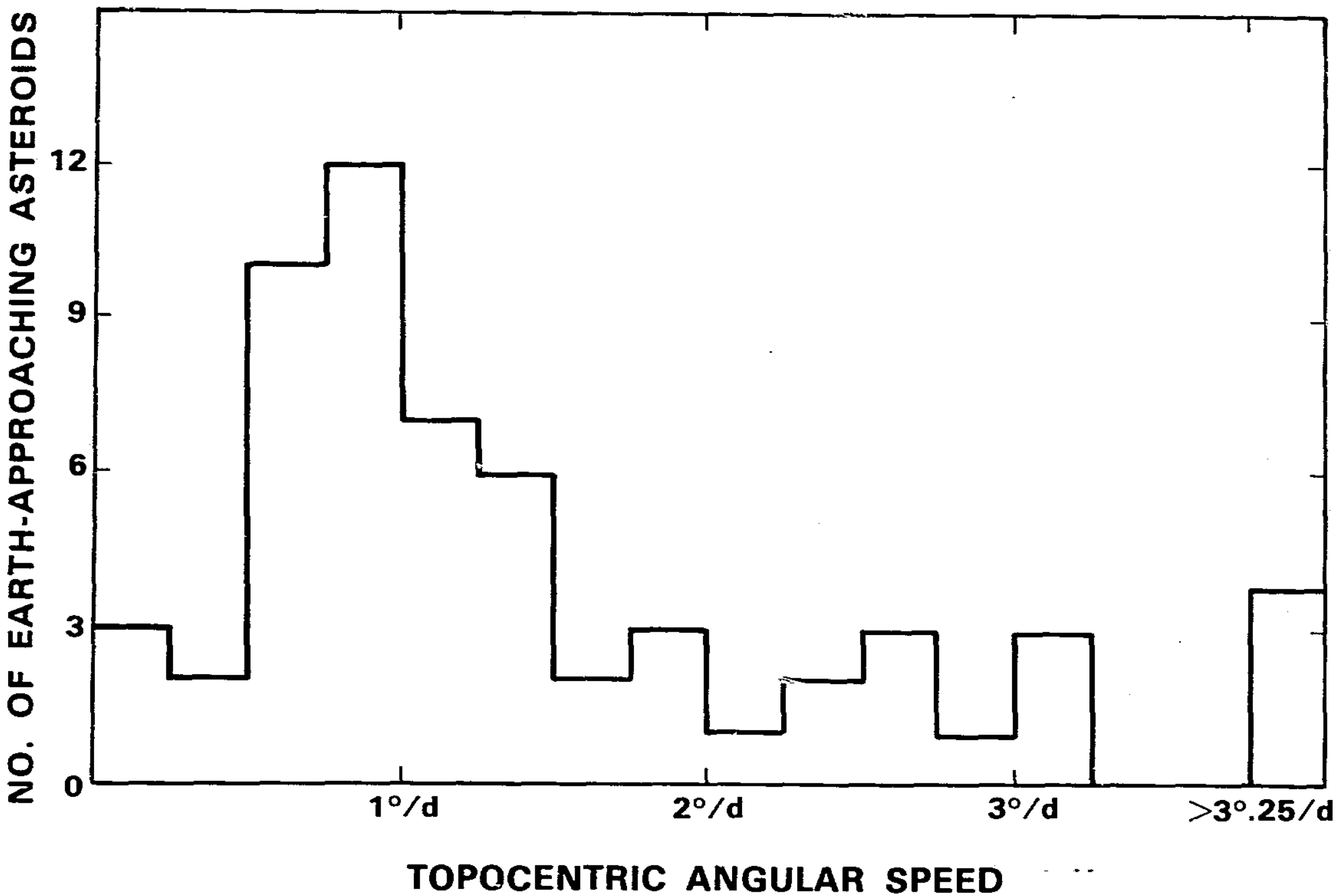
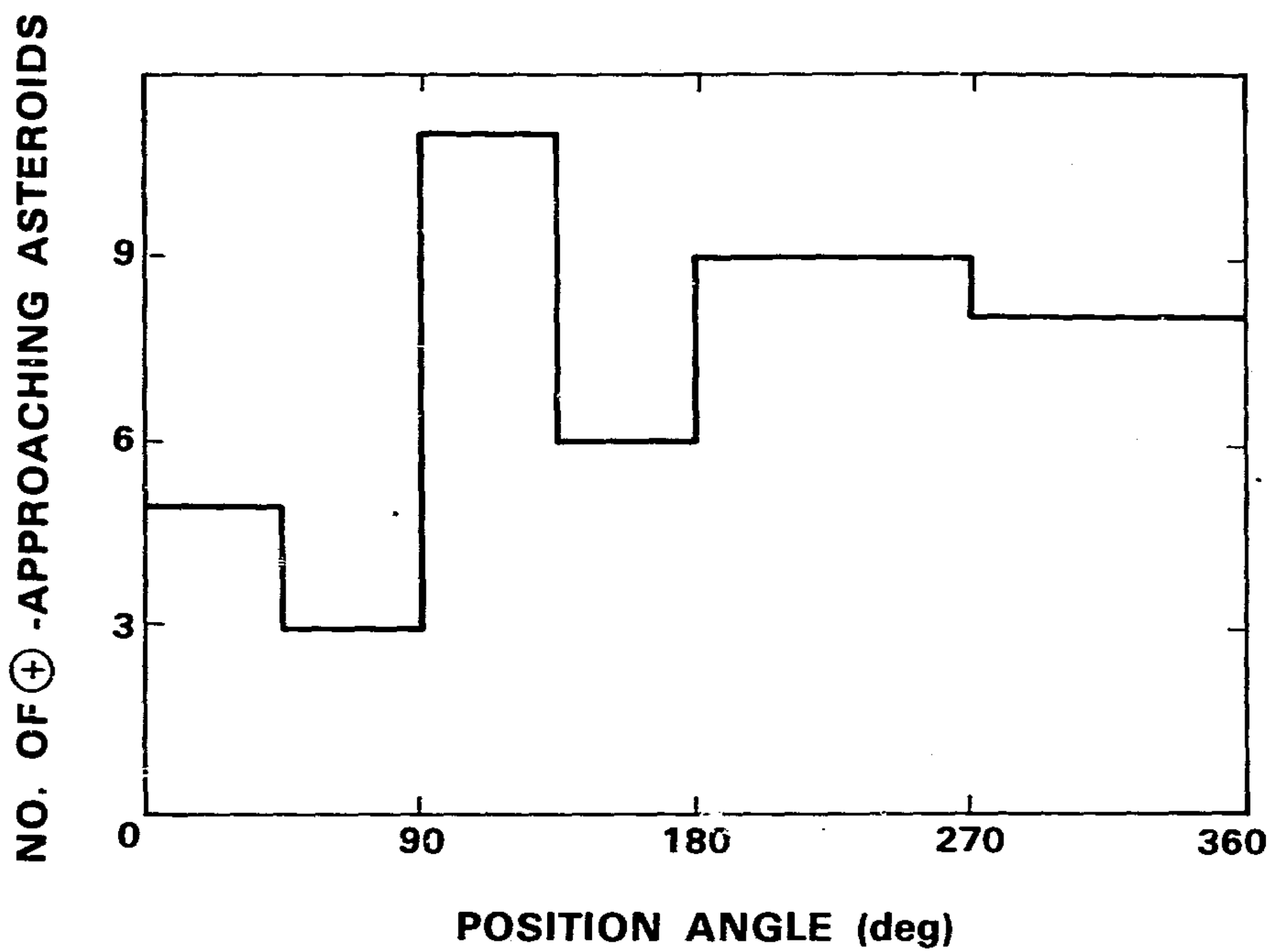


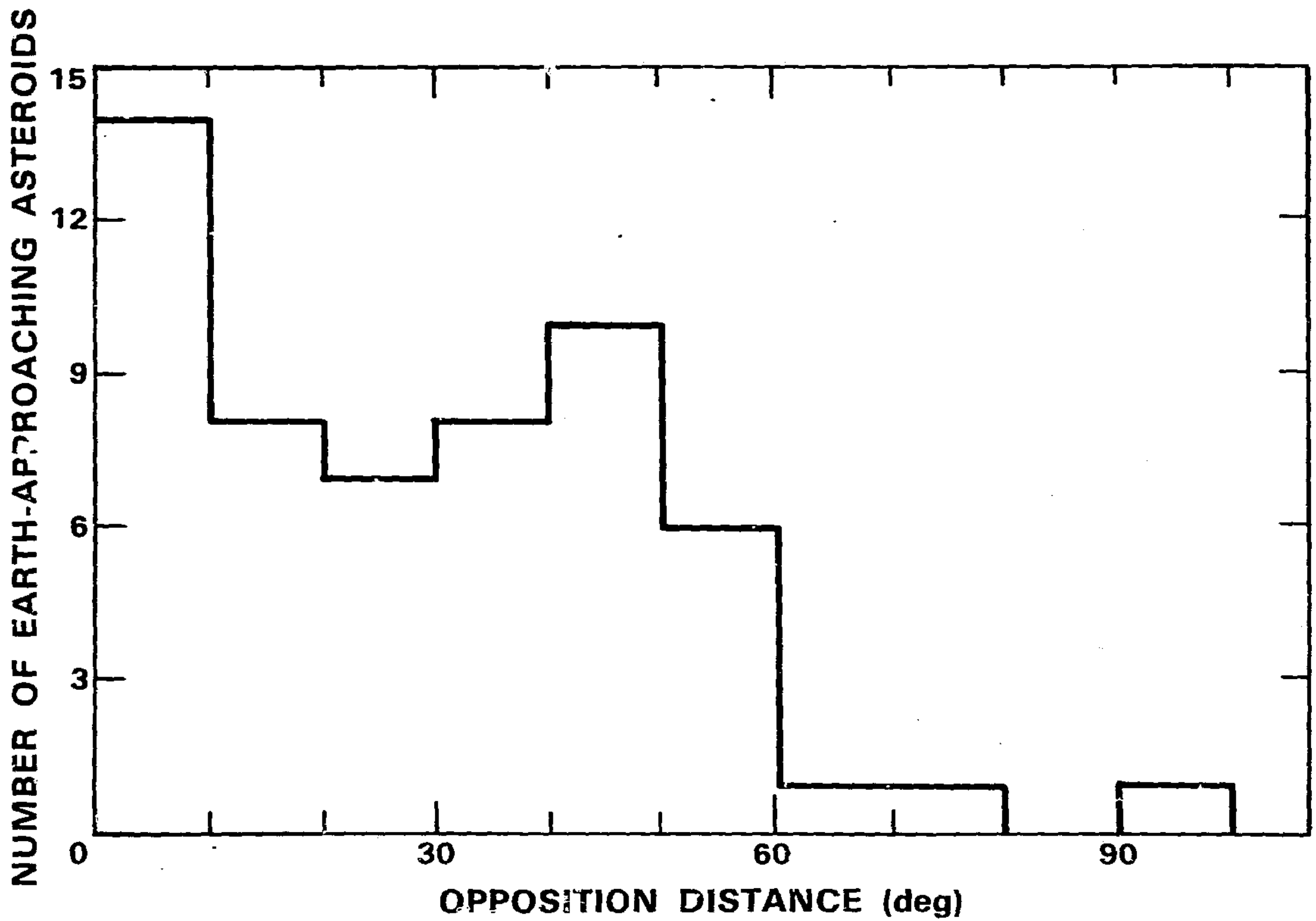
Fig 1

146192-N



146193-N

Fig 2


NUMBER OF EARTH-APPROACHING ASTEROIDS
0
3
6
9
12
15
30
60
90
OPPOSITION DISTANCE (deg)

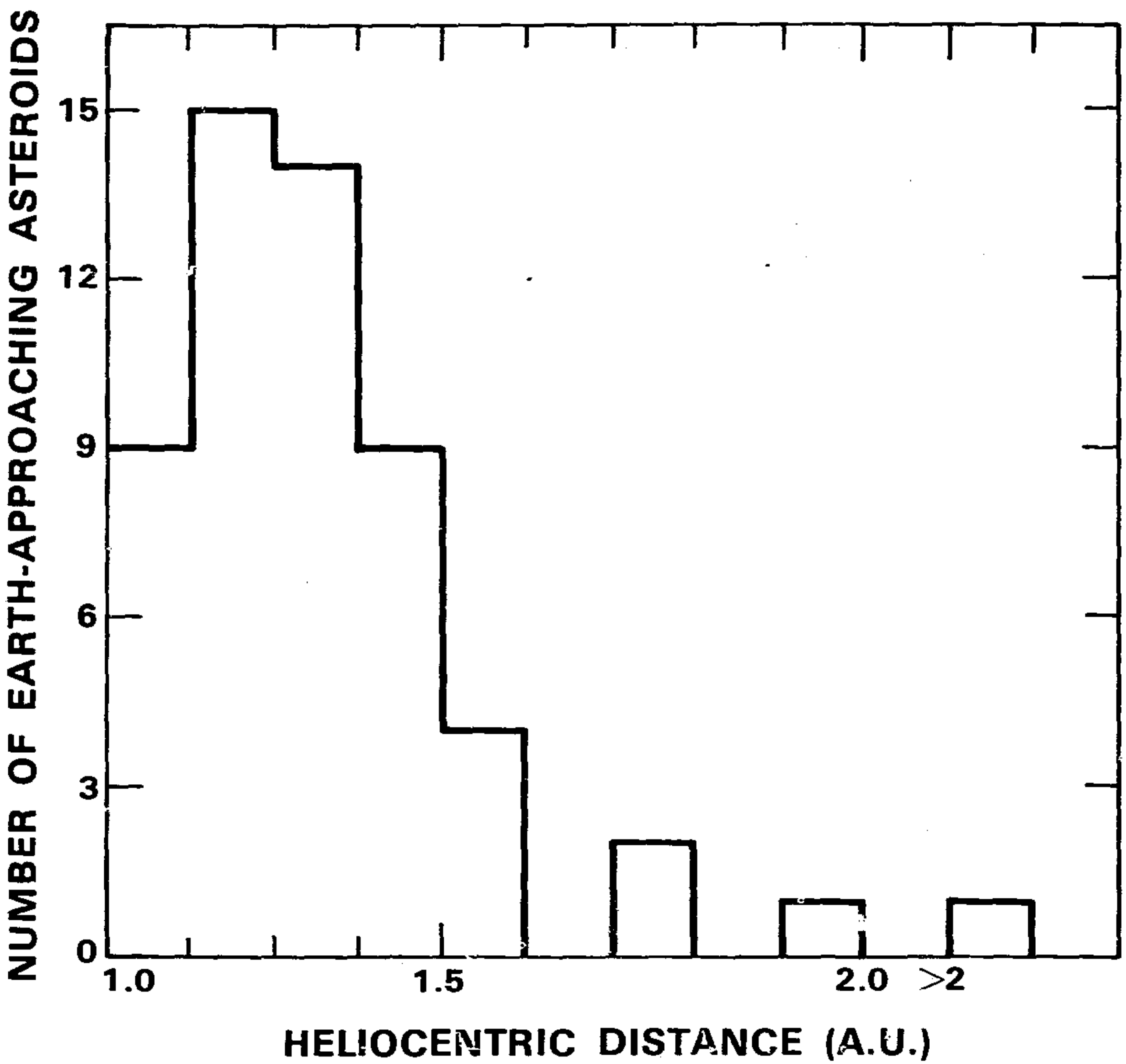

NUMBER OF EARTH-APPROACHING ASTEROIDS
0
3
6
9
12
15
1.0
1.5
2.0
>2
HELIOCENTRIC DISTANCE (A.U.)

Table I. Data on Earth-approaching Asteroids

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1963UA	2308	3016	0.89:[b]	136:[b]	0.44	1.25	0.25	2.5	3.1
1968AA	2845	3017	0.39:	324:	0.51	1.48	0.71	34.6	58.7
1971FA	3895	3754	0.64	274	0.48	1.86	0.86	0.7	1.4
1971SC	3299	5032	0.51	165	0.75	1.37	0.37	7.7	10.5
1971UA	3896	3755	1.08	223	0.76	1.36	0.37	1.9	2.5
1972RA	3381	4659	0.77:	130:	0.46	1.23	0.22	4.6	5.6
1972RB	3381	4659	1.23	108	0.76	1.14	0.13	4.7	5.3
1972XA	3618	3756	1.44	324	0.50	1.18	0.23	29.8	36.5
1973EA	3525	4010	1.20	282	0.57	1.29	0.41	36.1	50.1
1973EC	3525	3899	0.80:	150:	0.80	1.14	0.23	47.2	57.0
1973NA	3601	4659	11.90	206	0.62	1.11	0.09	14.6	16.0
1974MA	3712	4659	0.91	31	0.73	1.40	0.68	43.4	70.5
1974UB	3813	3910	0.88:	304:	0.67	1.68	0.69	5.7	9.5
1975TB	5393	4541	2.43	210	0.40	1.13	0.16	32.9	37.9

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1975YA	3918	3919	20.32	337	0.29	1.02	0.05	40.2	42.0
1976AA	3918	3919	2.51	328	0.67	1.11	0.13	7.1	8.0
1976UA	4395	4659	15.17	151	0.48	1.01	0.01	39.7	40.2
1976WA	4147	4660	0.58	14	0.41	1.36	0.61	41.8	66.3
1977HA	4193	4660	0.62	103	0.45	1.13	0.17	40.1	46.4
1977HB	4193	4406	1.24	256	0.68	1.19	0.18	1.5	1.8
1977RA	4392	4660	0.23:	39:	0.24	1.24	0.25	17.8	22.2
1977VA	4396	4660	0.83:	100:	0.42	1.13	0.14	5.0	5.7
1978CA	4392	4660	0.60:	352:	0.51	1.20	0.28	36.2	45.9
1978DA	4392	6827	0.77:	79:	0.81	1.20	0.24	25.3	31.2
1978RA	4496	4541	1.96	218	0.78	1.19	0.19	5.2	6.2
1978SB	4569	4661	1.29:	289:	0.38	1.32	0.33	15.3	20.3
1978VB2	4724	--	--	--	0.53	--	--	--	--
1979QA	4904	--	1.59:	280:	0.48	--	--	--	--

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1979QB	4904	5515	0.17	354	0.48	1.34	0.33	4.2	5.6
1979VA	5120	5319	1.76	93	0.37	1.12	0.15	22.4	25.7
1979XA	5121	5176	1.32	257	0.32	1.24	0.31	29.6	38.6
1979XB	5120	5131	3.87	235	0.26	1.03	0.09	49.8	53.7
1980AA	5138	5279	2.58:	120:	0.39	1.05	0.07	12.2	13.1
1980PA	5514	5899	0.83	53	0.32	1.27	0.31	32.1	41.6
1980RB1	5594	5847	0.60	292	0.63	1.64	0.64	6.4	10.4
1980WF	5669	5841	1.07	136	0.24	1.13	0.14	7.7	8.8
1980YS	5827	5899	0.11	1	0.29	1.23	0.26	7.7	9.7
1981CW	5886	5977	0.67	64	0.57	1.19	0.30	42.2	53.9
1981ET3	7093	7234	0.34	267	0.39	2.50	1.56	9.4	24.4
1981JD	6036	---	3.14	240	0.68	--	--	--	--
1981QA	6237	6702	0.91	127	0.21	1.19	0.20	26.3	31.4
1981QB	6254	6702	1.48	192	0.43	1.40	0.40	8.4	11.8

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentic Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1981VA	6481	6702	2.19	196	0.74	1.22	0.29	32.5	41.5
1982BB	6674	6703	0.75	342	0.35	1.40	0.50	27.5	41.1
1982CA	6769	--	1.88:	248:	0.17	--	--	--	--
1982DB	6675	6831	0.74	282	0.68	1.06	0.11	47.7	52.3
1982DV	6690	6831	0.73	128	0.67	1.20	0.26	31.6	39.5
1982EA	6770	--	0.65	266	0.78	--	--	--	--
1982FT	6877	8538	1.07	211	0.66	1.31	0.36	26.3	35.5
1982HR	3692[a]	7840	2.49:	264:	0.54	1.05	0.06	38.4	40.4
1982RA	7202	7602	1.70	334	0.33	1.24	0.32	37.4	48.5
1982RB	3725[a]	7602	1.05	168	0.36	1.33	0.34	15.6	20.8
1982TA	7342	8539	0.93	263	0.27	1.48	0.50	13.8	20.6
1982XB	7563	7841	3.01	31	0.45	1.02	0.05	33.7	35.2
1982YA	3758[a]	8534	2.61:	190:	0.71	1.22	0.24	2.6	3.2
1983LB	8014	8056	1.48	205	0.59	1.31	0.30	10.4	13.5

Table I. Data on Earth-approaching Asteroids (Cont'd.)

Designation	Discovery Reference[a]	Element Set Reference[a]	Angular Speed (°/d)	Position Angle (°)	Lunar Phase	Heliocentric Distance (A.U.)	Geocentric Distance (A.U.)	Phase Angle(°)	Opposition Distance(°)
1983LC	8014	8056	0.80	295	0.59	1.23	0.23	13.4	16.4
1983RB	8119	8394	1.30	160	0.49	1.29	0.30	12.2	15.7
1983RD	3862[a]	8534	2.90	113	0.50	1.10	0.10	21.8	23.9
1983TB	8192	8278	3.09	93	0.64	1.03	0.38	74.6	96.0

[a] References marked by this symbol refer to an I.A.U. Circular. All others are MPC numbers.

[b] Colons indicate less certain values.