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NEW OSCULATING ORBITS FOR 110 COMETS AND ANALYSIS OF ORIGINAL ORBITS FOR 200 COMETS

B. G. MARSDEN AND Z. SEKANINA
Center for Astrophysics, Harvard College Observatory and Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138

E. EVERHART
Department of Physics, University of Denver, Denver, Colorado 80208
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ABSTRACT

New osculating orbits are presented for 110 nearly parabolic comets. Combining these with selected orbit determinations from other sources, we consider a total of 200 orbits where the available observations yield a result of very good (first class) or good (second class) quality. For each of these, the original and future orbits (referred to the barycenter of the solar system) are calculated. The Oort effect (a tendency for original $1/a$ values to range from 0 to $+100\times10^{-6}$ AU^{-1}) is clearly seen among the first-class orbits but not among the second-class orbits. Modifications in original $1/a$ values due to the effects of nongravitational forces are considered.

I. INTRODUCTION

The main reason for this study is to assemble high-quality dynamical data on comets with nearly parabolic orbits (hereafter called nearly parabolic comets). Specifically, we derive heliocentric orbits for osculating epochs near perihelion passage and then calculate the "original" and "future" barycentric orbits (referred to the center of mass of the solar system) before and after the comets are subject to appreciable planetary perturbations. In an earlier paper (Marsden and Sekanina 1973) we established that the "Oort effect"—the tendency for the original reciprocal semimajor axes $(1/a)_{orig}$ to cluster around small positive values—is extremely pronounced in the case of comets of large perihelion distance q. We found that 17 of the 22 best-determined nearly parabolic orbits with $q > 2.2$ AU had values of $(1/a)_{orig}$ clustering around +34 units (1 unit = 10^{-6} AU^{-1}), and none had $(1/a)_{orig} > +700$ units. Since planetary perturbations typically change $1/a$ by several hundred units during one revolution about the Sun, we were forced to conclude, following Oort, that the great majority of these comets were making their first passage through the inner part of the solar system.

The computations presented here are restricted to comets with revolution periods greater than 200 yr. Short-period comets, particularly those with periods less than about 20 yr, represent a different situation. Their recent orbital evolution is primarily due to the direct action of Jupiter (Everhart 1972, 1976).

Oort's (1950) own initial investigation of the distribution of $(1/a)_{orig}$ was based on 19 nearly parabolic comets, only four of which had $q > 2.2$ AU. Our previous study was restricted to comets of large q in order to minimize the influence of nongravitational forces. Nevertheless, if there is indeed a difference in the Oort effect for comets of small and large q, it is now necessary to determine the orbits of nearly parabolic comets of small q as reliably as possible. If individual results cannot be trusted, we remark that since the radial component of the nongravitational force is expected to be positive outward from the Sun, the values of $1/a$ should be *systematically* in error, in the sense that the original orbits will appear to be more hyperbolic than they really are (Marsden, Sekanina, and Yeomans 1973).

II. NEW GRAVITATIONAL ORBIT DETERMINATIONS

In Table I we give the results of our orbit determinations for 110 single-apparation comets. These computations have been made by the first two authors of this paper, perturbations by all nine planets being taken into account. Although in many instances our calculations merely confirm those made previously by other investigators, they are nonetheless of value because the mean errors of $1/a$ are derived in a uniform way. Until a redetermination is made one does not know whether it is possible to rely on an earlier computation. For example, the previous result for the well-observed comet 1907 IV by Baehr (1933) turned out to be very accurate, although planetary perturbations were not allowed for during the arc of more than 12 months covered by the observations. On the other hand, the orbital elements for comet 1912 II by Peisino and de Caro (1931) are completely erroneous, in part because these authors did not realize that the reference-star position for the crucial final observation required correction by exactly 10^s in right ascension.

To this sample of 110 orbits we add 20 of the large-q orbits given in Table I of Marsden and Sekanina (1973) (except that those of comets 1947 VIII, 1950 I, and 1972 IX are recalculated here), as well as the orbits of comets

1892 VI, 1911 V, 1911 VI, and 1965 VIII, which we have published elsewhere (Marsden 1967; Van Biesbroeck, Vesely, and Marsden 1974, 1976).

III. ACCURACY OF THE ORBITS

We have classified the accuracy of the orbit determinations according to a quantity Q defined by

$$Q = \tfrac{1}{2}(L + M + N) + \delta, \qquad (1)$$

where the integers L, M, and N depend, respectively, on the mean error of the determination of the osculating $1/a$, the span of time covered by the observations, and the number of planets whose perturbations were taken into account, following the scheme in Table II. The quantity δ is taken to be $\tfrac{1}{2}$ or 1 in order to make Q integral, and hence $0 \le Q \le 9$. If $Q = 9$, 8, or 7, the orbit is put in class I ($Q = 9$ or 8 being subdivided into class IA, $Q = 7$ into class IB), and if $Q = 6$ or 5 it is in class II ($Q = 6$ corresponding to class IIA, $Q = 5$ to class IIB). Cases where $Q < 5$ (which include all the parabolic approximations and orbits where no perturbations were considered) are not of interest to us here. The above criterion for establishing accuracy classes for orbits will favor our own computations, where $N = 3$, and it will also favor comets of large q, where frequently $L > 4$ and $M > 5$, a combination that will lead to a class I orbit. We feel that these biases are appropriate and so have refrained from adding further criteria to Eq. (1), such as direct dependence on q, the range in true anomaly, the mean residual, consideration of the number of observations used and their distribution with time, and whether normal places were utilized.

The criterion Q yields 111 orbits of class I and 89 orbits of class II. Although further orbit computations will cause these numbers to increase as comets are observed in the future, it is unlikely that additional recalculations of the orbits of past comets (66 of these results are from various earlier calculations) will cause more than a few changes and additions to these classifications.

IV. ORIGINAL AND FUTURE ORBITS

The heliocentric osculating values $(1/a)_{osc}$ can be converted to the corresponding barycentric $(1/a)_{orig}$ and $(1/a)_{fut}$ by adding to them the quantities $-u_b$ and $+u_a$, defined and listed for the comets of the 19th and 20th centuries by Everhart and Raghavan (1970). In that compilation the departure from parabolic motion was ignored, and in cases where this departure is relatively large, the results require significant correction. Accordingly, the third author has recalculated the values of $-u_b$ and u_a. The present method involves a numerical integration of the path of the comet accurate to the 15th order in the step size and taking into account the perturbations by all nine planets. The comet is followed from its position at the epoch backward and forward in time until it is 60 AU from the Sun. The integrator used for these barycentric $(1/a)_{orig}$ and $(1/a)_{fut}$ calculations is an implicit single-sequence method (Everhart 1974a, 1974b), which is very efficient for this purpose. In the several cases where the first two authors checked these results, the difference in $(1/a)_{orig}$ was rarely as large as 0.1 unit.

Table III includes the resulting 200 values of $(1/a)_{orig}$ and $(1/a)_{fut}$, arranged in order of q and separated by comet class. In accordance with the resolution adopted by IAU Commission 20 in 1970 (Roemer 1971), $(1/a)_{osc}$ (given here with its mean error) and the quantities u_b and u_a are in each case referred to the standard 40-day Julian date closest to perihelion passage. The values of $u_b(p)$ and $u_a(p)$ that correspond to an osculation epoch exactly at perihelion passage are also listed. Asterisks in the final column identify the 12 class I and 54 class II orbits that were not determined as part of the sample mentioned in Sec. II. These other orbits are generally those tabulated in the comet catalog (Marsden 1975a), except that the class II orbits for comets 1840 IV, 1844 II, 1847 II, 1849 II, and 1850 I are from recent calculations by Buckley (1976). Where necessary the starting elements were adjusted to the official osculation epochs.

Even a cursory examination of the class I values of $(1/a)_{orig}$ given in Table III confirms that the Oort effect is much more obvious for the comets of largest q, which enforces our earlier conclusion (Marsden and Sekanina 1973) that most comets of $q \gtrsim 2$ AU do not survive as readily discoverable objects after their first approaches to the Sun. We remark that the largest $(1/a)_{orig}$ among nearly parabolic comets of $q > 2.0$ AU belongs to the highly unusual comet 1962 VIII, which was extremely active at large heliocentric distances. The largest class I $(1/a)_{orig}$ for $q > 3.0$ AU refers to comet 1927 IV, which was intrinsically very bright and also active far from the Sun. We note that among class I comets the only entry between $(1/a)_{orig} = +89$ and $+227$ units refers to 1908 III, another physically unusual comet. The gap suggests that it is reasonable to limit "new" comets, i.e., comets that are *probably* making their first passage through the inner part of the solar system, to those with $(1/a)_{orig} <$ +100 units.

V. STATISTICAL ANALYSIS OF ORIGINAL ORBITS

Table IV gives a statistical analysis of the $(1/a)_{orig}$ data in Table III. The upper section refers to the class I orbits, the lower section to the class II orbits. In each range of q the first three columns give some indication of the spread in $(1/a)_{orig}$, the quantities listed being the means (with each orbit regarded as of unit weight) of the overlapping lower, middle, and upper halves of the $(1/a)_{orig}$ distribution. The mean $(1/a)_{orig}$ and the number of "new" comets are also tabulated.

TABLE I. Gravitational orbital elements.

1844 III (41, 1".81)	1886 I (142, 2".72)	1886 V (69, 2".67)	1886 IX (62, 2".24)	1888 I (186, 2".01)	1888 V (54, 2".45)	1889 I (173, 1".69)	1889 IV (92, 1".87)	1892 I (81, 1".78)	1892 II (48, 1".65)
44 Dec. 20.0	86 Apr. 4.0	86 June 23.0	86 Nov. 30.0	88 Mar. 24.0	88 Aug. 31.0	89 Feb. 7.0	89 July 17.0	92 Apr. 12.0	92 May 22.0
44 Dec. 14.19135 ± 18	86 Apr. 6.45552 ± 9	86 June 7.88543 ± 29	86 Dec. 16.99680 ± 16	88 Mar. 17.50208 ± 9	88 Sept.13.28237 ± 138	89 Jan. 31.66816 ± 20	89 July 19.78398 ± 71	92 Apr. 7.15170 ± 18	92 May 11.72748 ± 134
177.49802 ± 924	126.58395 ± 8	201.28928 ± 63	86.34447 ± 27	359.91413 ± 19	290.80404 ± 203	340.46254 ± 22	345.86852 ± 55	24.50696 ± 25	129.32530 ± 65
119.89773 ± 352	37.26494 ± 8	193.50589 ± 119	138.27194 ± 24	246.25697 ± 32	138.39365 ± 25	358.27493 ± 22	287.01029 ± 84	241.72366 ± 23	254.24043 ± 13
45.56890 ± 128	82.62578 ± 19	87.66771 ± 50	101.62064 ± 34	42.25032 ± 7	56.34778 ± 129	166.37774 ± 4	65.98910 ± 133	38.70278 ± 9	89.69711 ± 18
0.2505373 ± 468	0.6423704 ± 12	0.2698035 ± 31	0.6633168 ± 18	0.6987724 ± 12	1.5278525 ± 466	1.8149162 ± 11	1.0397207 ± 47	1.0268320 ± 29	1.9707259 ± 112
0.9993023 ± 753	1.0004550 ± 53	0.9967833 ± 234	1.0004077 ± 126	0.9958742 ± 77	0.9914884 ± 524	1.0012295 ± 48	0.9976110 ±1357	0.9987309 ± 140	1.0003714 ± 273
44 Dec. 27 - 45 Mar. 9	85 Dec. 2 - 86 July 20	86 Apr. 29 - 86 July 30	86 Oct. 7 - 87 May 31	88 Feb. 19 - 88 Sept. 7	88 Oct. 31 - 89 May 20	88 Sept. 3 - 90 July 19	89 July 22 - 89 Nov. 14	92 Mar. 8 - 93 Feb. 16	92 Mar. 19 - 93 Jan. 12
1895 IV (78, 1".59)	1897 I (44, 1".60)	1898 I (171, 1".64)	1898 VII (69, 1".60)	1899 I (124, 1".87)	1900 I (32, 1".52)	1903 IV (239, 1".76)	1904 II (48, 1".69)	1907 I (67, 1".65)	1907 IV (143, 1".68)
96 Jan. 2.0	97 Feb. 5.0	98 Mar. 12.0	98 Sept.28.0	99 Apr. 16.0	00 Apr. 11.0	03 Sept. 3.0	04 Nov. 16.0	07 Mar. 6.0	07 Sept.22.0
95 Dec. 18.82918 ± 7	97 Feb. 8.60400 ± 47	98 Mar. 17.63196 ± 91	98 Sept.14.54530 ± 50	99 Apr. 13.47811 ± 8	00 Apr. 29.41083 ± 159	03 Aug. 28.10866 ± 5	04 Nov. 3.80481 ±1085	07 Mar. 19.60915 ± 155	07 Sept. 4.46171 ± 6
272.67232 ± 25	172.32770 ± 44	47.31414 ± 122	233.26244 ± 29	8.70402 ± 40	24.40097 ± 80	127.25781 ± 14	40.74532 ± 554	317.10944 ± 73	294.45098 ± 42
321.26140 ± 31	87.22329 ± 32	263.16749 ± 41	74.71246 ± 8	25.70454 ± 26	41.08863 ± 57	294.21089 ± 4	219.09128 ± 70	97.77763 ± 20	143.58852 ± 44
141.62085 ± 12	146.13679 ± 13	72.52941 ± 22	69.93469 ± 12	146.26344 ± 14	146.44411 ± 20	85.01231 ± 15	99.60360 ± 41	141.66098 ± 17	8.96327 ± 7
0.1919784 ± 9	1.0627908 ± 31	1.0952606 ± 128	1.7015952 ± 26	0.3265758 ± 12	1.3315289 ± 135	0.3301822 ± 9	1.8820493 ± 827	2.0517051 ± 150	0.5121730 ± 10
1.0000509 ± 15	1.0009827 ± 181	0.9804544 ± 374	1.0009345 ± 125	1.0003570 ± 29	1.0010581 ± 398	1.0004061 ± 20	1.0006783 ±1858	1.0010029 ± 384	0.9987941 ± 34
95 Nov. 18 - 96 Aug. 9	96 Nov. 4 - 97 Apr. 27	98 Mar. 20 - 98 Nov. 13	98 June 12 - 99 Dec. 7	99 Mar. 5 - 99 Aug. 11	00 Feb. 3 - 00 Aug. 18	03 June 22 - 03 Oct. 23	04 Dec. 18 - 05 May 2	07 Mar. 9 - 08 Feb. 26	07 June 15 - 08 June 27
1908 III (141, 2".46)	1910 IV (200, 1".71)	1911 II (86, 1".92)	1911 IV (66, 2".49)	1912 II (170, 1".68)	1914 II (62, 1".66)	1914 IV (59, 1".64)	1914 V (339, 1".81)	1915 II (217, 2".72)	1917 III (186, 1".44)
09 Jan. 14.0	10 Sept. 6.0	11 June 13.0	11 Oct. 11.0	12 Oct. 5.0	14 May 28.0	14 Aug. 16.0	14 Nov. 4.0	15 July 2.0	17 June 21.0
08 Dec. 26.25710 ± 16	10 Sept.16.77998 ± 179	11 June 30.67622 ± 130	11 Oct. 10.76383 ± 11	12 Oct. 5.45310 ± 8	14 June 4.69380 ± 25	14 Aug. 5.47082 ± 573	14 Oct. 26.76644 ± 10	15 July 17.64931 ± 9	17 June 17.07345 ± 28
171.58531 ± 23	50.96426 ± 94	110.36777 ± 296	71.70465 ± 57	25.62718 ± 13	72.23209 ± 27	270.34600 ± 972	97.46071 ± 4	247.77409 ± 7	120.62385 ± 16
103.75364 ± 27	290.08488 ± 31	157.96379 ± 26	89.19759 ± 55	297.54795 ± 15	199.41160 ± 29	0.88450 ± 86	59.70010 ± 3	72.75910 ± 5	183.75658 ± 6
140.17745 ± 8	121.05277 ± 10	148.42646 ± 39	96.46640 ± 77	79.80614 ± 12	23.91971 ± 32	77.82948 ± 437	68.03606 ± 7	54.79233 ± 11	25.66559 ± 5
0.9452989 ± 14	1.9480128 ± 231	0.6838369 ± 180	0.3034237 ± 12	0.7160786 ± 10	1.1985269 ± 50	0.7127565 ± 646	1.1044588 ± 11	1.0053194 ± 7	1.6864456 ± 11
1.0006719 ± 63	0.9997975 ± 205	0.9962962 ± 434	1.0001466 ± 143	1.0004512 ± 46	1.0001059 ± 319	0.9986655 ±2133	1.0001549 ± 20	1.0003113 ± 50	0.9994052 ± 58
08 Sept. 3 - 09 May 11	10 Aug. 11 - 11 June 16	11 July 9 - 11 Sept.18	11 Sept.30 - 12 Feb. 17	12 Sept.10 - 13 May 26	14 Mar. 31 - 14 Sept.23	14 Sept.20 - 14 Nov. 17	13 Dec. 18 - 15 Sept. 7	15 Feb. 16 - 16 Sept.26	16 Apr. 4 - 18 Jan. 29
1919 V (87, 1".47)	1920 III (34, 1".36)	1921 II (146, 1".64)	1924 I (63, 2".17)	1925 I (201, 1".54)	1925 VII (129, 1".43)	1927 IX (34, 1".87)	1931 III (86, 1".20)	1932 VII (48, 1".16)	1937 IV (136, 1".47)
19 Nov. 18.0	20 Dec. 22.0	21 Apr. 21.0	24 Feb. 25.0	25 Mar. 31.0	25 Oct. 17.0	27 Dec. 26.0	31 June 28.0	32 Sept.10.0	37 July 6.0
19 Dec. 7.80919 ± 90	20 Dec. 11.50742 ± 26	21 May 10.44958 ± 9	24 Mar. 13.94926 ± 910	25 Apr. 1.50651 ± 42	25 Oct. 2.97299 ± 40	27 Dec. 18.18085 ± 26	31 June 11.76749 ± 77	32 Sept.24.55050 ± 67	37 June 20.06241 ± 57
185.74608 ± 93	340.87163 ± 43	64.49891 ± 18	271.43414 ± 498	36.18536 ± 49	106.40210 ± 73	47.15235 ± 203	320.14952 ± 170	69.79329 ± 39	107.72728 ± 34
121.40389 ± 25	108.14869 ± 74	268.74681 ± 14	114.37708 ± 110	318.41178 ± 10	334.91258 ± 5	77.54558 ± 41	191.53948 ± 32	245.38984 ± 21	127.91505 ± 13
46.38616 ± 12	22.03289 ± 144	132.18713 ± 7	72.33056 ± 135	100.01717 ± 9	49.32460 ± 51	85.11174 ± 74	42.30194 ± 17	78.39156 ± 12	41.55598 ± 9
1.1152912 ± 83	1.1478923 ± 142	1.0084570 ± 6	1.7556946 ± 814	1.1094769 ± 45	1.5662429 ± 183	0.1761570 ± 102	1.0469028 ± 216	1.6474121 ± 84	1.7337911 ± 44
1.0002216 ± 368	0.9940806 ±1291	1.0003571 ± 113	0.9985985 ±2278	1.0006050 ± 124	1.0003823 ± 192	0.9998399 ± 158	0.9792034 ± 203	1.0006017 ± 250	1.0001374 ± 140
19 Aug. 25 - 20 Feb. 3	20 Dec. 15 - 21 Mar. 10	21 Mar. 15 - 21 Nov. 26	24 Mar. 30 - 24 Oct. 7	25 Apr. 6 - 26 May 2	25 Nov. 17 - 26 May 31	27 Dec. 5 - 28 Mar. 29	31 July 18 - 32 Apr. 9	32 June 21 - 32 Dec. 30	37 Feb. 4 - 37 Oct. 25
1937 V (212, 1".54)	1940 III (19, 1".72)	1940 IV (51, 2".06)	1941 I (189, 1".24)	1941 IV (130, 1".37)	1943 I (166, 1".45)	1945 I (22, 1".22)	1946 I (183, 1".41)	1946 VI (101, 0".96)	1947 IV (27, 2".01)
37 Aug. 15.0	40 July 30.0	40 Oct. 18.0	41 Jan. 6.0	41 Feb. 15.0	43 Feb. 5.0	44 Dec. 16.0	46 Apr. 10.0	46 Oct. 27.0	47 May 15.0
37 Aug. 15.66577 ± 13	40 Aug. 15.75921 ±1424	40 Oct. 8.24909 ± 53	41 Jan. 16.23396 ± 5	41 Jan. 27.65771 ± 9	43 Feb. 6.72111 ± 15	45 Jan. 4.06221 ± 425	46 Apr. 13.26324 ± 32	46 Oct. 26.77914 ± 45	47 May 20.96280 ± 16
114.82599 ± 28	329.67159 ±2768	235.73160 ± 49	199.57635 ± 7	268.67619 ± 36	39.82451 ± 14	238.93048 ± 89	54.32307 ± 19	320.41996 ± 25	303.75483 ± 39
58.71336 ± 19	127.36545 ± 448	134.36607 ± 13	295.88727 ± 10	42.38527 ± 35	100.11797 ± 6	28.39783 ± 48	128.96788 ± 4	237.63325 ± 18	353.21105 ± 41
146.41272 ± 15	133.11849 ± 73	54.69555 ± 73	49.89085 ± 11	168.19948 ± 5	19.71437 ± 7	17.28274 ± 21	72.84720 ± 5	56.96770 ± 6	39.29494 ± 36
0.8627435 ± 4	1.0617681 ±3236	1.0822279 ± 50	0.3677514 ± 20	0.7900335 ± 6	1.3536467 ± 23	2.4108560 ± 75	1.7241292 ± 25	1.1361133 ± 25	0.5597988 ± 19
0.9999854 ± 249	1.0014588 ±3358	0.9808432 ± 381	1.0004851 ± 36	0.9991021 ± 126	0.9921959 ± 85	0.9935001 ± 658	1.0011691 ± 57	1.0007764 ± 49	0.9974272 ± 68
37 July 4 - 37 Dec. 30	40 Oct. 4 - 41 Jan. 2	40 Aug. 1 - 41 Jan. 1	40 Sept.19 - 41 June 17	41 Jan. 19 - 41 Sept.17	42 Nov. 17 - 43 Aug. 1	44 May 22 - 45 Nov. 30	46 Feb. 2 - 47 Aug. 9	46 Aug. 16 - 48 Nov. 23	47 Mar. 26 - 47 Sept.21
1947 VIII (26, 0".88)	1948 I (123, 1".83)	1948 II (78, 1".00)	1948 V (95, 1".30)	1948 X (24, 1".76)	1950 I (64, 1".10)	1951 I (38, 1".10)	1952 I (116, 1".25)	1953 I (66, 1".13)	1953 II (64, 1".08)
47 Sept.12.0	48 Feb. 19.0	48 Feb. 19.0	48 May 9.0	48 Oct. 16.0	50 Feb. 8.0	51 Feb. 3.0	52 Jan. 29.0	53 Jan. 23.0	53 Jan. 23.0
47 Sept. 4.43104 ±1040	48 Feb. 16.42331 ± 8	48 Feb. 16.69227 ± 24	48 May 16.61233 ± 44	48 Oct. 22.86595 ± 1202	50 Jan. 19.31311 ± 54	51 Jan. 15.04291 ± 84	52 Jan. 12.94857 ± 4	53 Jan. 5.41771 ± 27	53 Jan. 24.85994 ± 8
73.45239 ± 187	350.22483 ± 17	61.92676 ± 19	66.90426 ± 20	274.20299 ± 931	40.09684 ± 12	192.46085 ± 22	269.60664 ± 14	191.63136 ± 15	253.82318 ± 16
121.41080 ± 22	270.74914 ± 20	198.60191 ± 6	246.95429 ± 7	66.97022 ± 199	221.63271 ± 7	38.18571 ± 12	76.18325 ± 15	220.69040 ± 6	342.88322 ± 12
155.08184 ± 27	140.56742 ± 7	77.53910 ± 6	92.92144 ± 6	87.60339 ± 153	131.35554 ± 8	144.15044 ± 7	152.53270 ± 8	59.11992 ± 8	97.17731 ± 13
3.2611017 ±1138	0.7481250 ± 8	1.4995569 ± 29	2.1070561 ± 36	1.2734282 ±1044	2.5532308 ± 23	2.5723350 ± 32	0.7404270 ± 5	1.6649768 ± 22	0.7777290 ± 8
1.0022784 ± 327	1.0003626 ± 28	1.0010851 ± 113	1.0007869 ± 81	0.9974986 ±3209	1.0007134 ± 119	1.0012313 ± 106	0.9997388 ± 51	0.9959099 ± 104	1.0003434 ± 67
48 Oct. 7 - 50 Aug. 17	47 Sept.28 - 49 Feb. 6	48 Jan. 18 - 48 Nov. 30	48 Mar. 13 - 50 Feb. 9	48 Nov. 24 - 49 Feb. 26	49 May 20 - 51 Mar. 8	50 May 27 - 53 Jan. 19	51 Aug. 7 - 52 Feb. 26	52 Aug. 20 - 53 June 29	52 Dec. 10 - 53 July 18
1953 III (51, 1".42)	1954 VIII (39, 0".98)	1954 X (82, 2".51)	1955 III (74, 1".37)	1955 V (102, 1".81)	1957 III (150, 1".69)	1957 V (108, 1".23)	1957 VI (37, 1".10)	1958 III (75, 1".08)	1959 I (85, 1".67)
53 May 23.0	54 May 18.0	54 June 27.0	55 June 22.0	55 Aug. 1.0	57 Mar. 23.0	57 July 21.0	57 Aug. 30.0	58 Apr. 27.0	59 Mar. 13.0
53 May 26.43575 ± 16	54 June 1.93501 ± 47	54 July 7.35141 ± 54	55 June 4.16690 ± 67	55 Aug. 4.06028 ± 126	57 Apr. 8.03261 ± 7	57 Aug. 1.43726 ± 7	57 Sept. 2.41371 ± 157	58 Apr. 16.30362 ± 19	59 Mar. 11.51979 ± 39
85.74640 ± 23	357.25436 ± 312	194.38384 ± 65	32.50902 ± 258	348.19480 ± 179	308.78070 ± 5	40.31348 ± 47	13.26952 ± 16	16.45592 ± 17	100.74005 ± 18
275.18745 ± 11	122.12366 ± 39	2.33254 ± 38	48.24341 ± 26	338.72332 ± 55	215.15908 ± 7	67.62521 ± 7	232.94930 ± 0	150.50538 ± 17	323.07833 ± 10
93.85613 ± 14	116.15814 ± 13	53.22254 ± 12	86.49775 ± 52	107.51585 ± 86	119.94901 ± 7	93.93917 ± 24	33.20518 ± 9	15.79381 ± 6	61.25202 ± 12
1.0221318 ± 16	0.6774609 ± 442	0.9701523 ± 55	0.5344188 ± 175	0.8846164 ± 16	0.3160584 ± 12	0.3549330 ± 28	4.4472617 ± 75	1.3226895 ± 27	1.6281980 ± 20
0.9973915 ± 88	1.0002856 ± 268	1.0008227 ± 241	0.9893612 ± 435	1.0009472 ±1073	1.0002463 ± 18	0.9993651 ± 47	1.0027452 ± 205	0.9999428 ± 183	0.9998662 ± 95
53 Apr. 14 - 54 Jan. 1	54 July 28 - 54 Dec. 18	53 Oct. 16 - 54 Sept.15	55 June 14 - 55 Sept. 8	55 July 30 - 55 Nov. 12	56 Nov. 8 - 58 Apr. 11	57 Aug. 5 - 58 July 9	56 Mar. 18 - 59 Sept. 3	58 Feb. 16 - 58 Sept.15	58 Sept. 7 - 60 Apr. 21
1959 IX (29, 0".76)	1960 II (37, 3".05)	1961 II (63, 1".25)	1961 VIII (56, 1".82)	1962 III (92, 1".79)	1962 VIII (243, 1".42)	1963 I (76, 1".16)	1963 V (33, 1".29)	1964 VI (16, 1".11)	1964 VIII (38, 2".17)
59 Nov. 8.0	60 Mar. 7.0	61 Jan. 21.0	61 Oct. 28.0	62 Apr. 6.0	62 Dec. 2.0	63 Apr. 1.0	63 Sept. 8.0	64 June 14.0	64 July 24.0
59 Nov. 13.21617 ± 63	60 Mar. 20.99679 ± 28	61 Feb. 8.91753 ± 69	61 Oct. 10.64082 ± 54	62 Apr. 1.66294 ± 5	62 Dec. 10.20495 ± 18	63 Mar. 21.47480 ± 5	63 Aug. 23.95638 ± 491	64 June 30.62159 ± 8	64 Aug. 1.21113 ± 422
84.67373 ± 64	306.64997 ± 83	136.61436 ± 45	126.58997 ± 107	11.47866 ± 8	233.55018 ± 7	336.28515 ± 35	86.15764 ±3348	58.43943 ± 40	290.80805 ± 213
99.93959 ± 13	251.96084 ± 80	176.57966 ± 38	246.67035 ± 13	303.97674 ± 12	154.73548 ± 6	52.50449 ± 37	7.23877 ±4894	309.18575 ± 41	269.29652 ± 361
19.63559 ± 11	159.60225 ± 36	150.96175 ± 22	155.71276 ± 18	65.01012 ± 31	153.28414 ± 4	160.64521 ± 4	144.57570 ± 552	161.82773 ± 45	171.91946 ± 36
1.2534641 ± 94	0.5044118 ± 17	1.0616121 ± 57	0.6811293 ± 48	0.0313967 ± 2	2.1334124 ± 11	0.6321387 ± 6	0.0050649 ± 146	0.5003635 ± 25	0.8217521 ± 52
0.9997478 ± 182	1.0002975 ± 118	0.9898998 ± 358	0.9918120 ± 212	1.0000033 ± 4	0.9895688 ± 24	0.9933768 ± 22	0.9999458 ± 5	0.9959331 ± 73	0.9846432 ±4397
59 Dec. 4 - 60 Sept.26	60 Jan. 4 - 60 June 17	60 Dec. 30 - 61 May 14	61 Oct. 11 - 61 Dec. 29	62 Feb. 7 - 63 Jan. 25	61 Sept. 6 - 65 Nov. 1	63 Jan. 4 - 63 Oct. 12	63 Sept.15 - 63 Dec. 18	64 June 11 - 65 Jan. 26	64 July 10 - 64 Sept. 4

1964 IX (37, 0".90)	1966 II (87, 1".10)	1967 II (46, 1".79)	1968 I (176, 1".24)	1968 VI (131, 1".16)	1969 IX (281, 1".16)	1970 II (391, 1".86)	1970 III (210, 1".22)	1970 XV (241, 1".29)	1971 I (14, 1".83)
64 Sept. 2.0	66 Apr. 25.0	67 Jan. 30.0	68 Mar. 5.0	68 Aug. 12.0	69 Dec. 5.0	70 Apr. 4.0	70 Apr. 4.0	70 Oct. 21.0	71 Jan. 9.0
64 Aug. 23.18630 ± 32	66 Apr. 17.79138 ± 704	67 Jan. 20.88434 ± 35	68 Feb. 25.70555 ± 40	68 Aug. 7.92314 ± 301	69 Dec. 21.26772 ± 4	70 Mar. 20.04539 ± 4	70 Mar. 21.63742 ± 20	70 Oct. 20.69897 ± 5	71 Jan. 6.53407 ±9971
20.69239 ± 37	136.16826 ± 274	79.74330 ± 97	70.87244 ± 25	88.70491 ± 201	267.82742 ± 6	354.15414 ± 6	123.47390 ± 9	96.57992 ± 5	128.68990 ± 816
279.74403 ± 31	166.99232 ± 145	75.04944 ± 93	254.62784 ± 9	106.04045 ± 61	100.96290 ± 4	223.95907 ± 13	301.05941 ± 5	21.00072 ± 5	24.00840 ± 631
67.96722 ± 9	28.71227 ± 268	9.07869 ± 26	129.31648 ± 4	143.24077 ± 30	75.81964 ± 8	90.04392 ± 5	86.30892 ± 5	126.71408 ± 5	175.61032 ± 89
1.2502751 ± 46	2.0187659 ± 711	0.4192254 ± 72	1.6965809 ± 20	1.1604335 ± 152	0.4726377 ± 4	0.5376225 ± 6	1.7190850 ± 13	1.1125387 ± 5	3.2765611 ±3039
0.9965132 ± 187	0.9981832 ±1477	1.0003909 ± 161	0.9991517 ± 115	1.0006653 ±1346	0.9999195 ± 21	0.9962867 ± 27	0.9991249 ± 65	1.0000484 ± 27	0.9969431 ±4547
64 Aug. 8 - 65 Feb. 25	66 Aug. 19 - 66 Nov. 7	66 Oct. 17 - 67 Feb. 8	67 Dec. 29 - 69 Nov. 4	68 July 13 - 68 Nov. 10	69 Oct. 13 - 70 Apr. 5	69 Dec. 30 - 70 Oct. 27	69 July 23 - 71 Feb. 21	70 July 5 - 71 Apr. 29	72 Mar. 16 - 73 Feb. 9

1971 V (131, 1".89)	1972 VIII (188, 1".28)	1972 IX (129, 1".41)	1972 XII (49, 0".93)	1973 II (255, 1".40)	1973 VII (38, 1".44)	1973 X (25, 2".25)	1973 XII (597, 1".45)	1974 III (159, 1".57)	1974 XII (41, 1".11)
71 Mar. 30.0	72 Oct. 10.0	72 Nov. 19.0	72 Dec. 29.0	73 Feb. 7.0	73 June 7.0	73 Nov. 14.0	73 Dec. 24.0	74 Mar. 14.0	74 Aug. 21.0
71 Apr. 17.25025 ± 165	72 Oct. 5.46392 ± 288	72 Nov. 14.80931 ± 448	72 Dec. 18.94479 ± 474	73 Feb. 12.27747 ± 29	73 June 7.18144 ± 65	73 Nov. 8.16508 ±1947	73 Dec. 28.43067 ± 2	74 Mar. 18.35638 ± 8	74 Aug. 7.77494 ±2084
152.35624 ± 157	346.23520 ± 97	56.66276 ± 68	267.20886 ± 67	334.29802 ± 14	74.85842 ± 40	72.55409 ± 251	37.82380 ± 11	333.12982 ± 24	151.76542 ± 199
103.37699 ± 34	175.17875 ± 13	224.78680 ± 14	314.18717 ± 11	42.48378 ± 9	164.11846 ± 7	278.54541 ± 57	257.76560 ± 12	143.03629 ± 32	225.40271 ± 8
109.68638 ± 38	138.63484 ± 13	79.37227 ± 9	113.08524 ± 6	141.85101 ± 5	121.60458 ± 17	137.40175 ± 16	14.30505 ± 3	61.29016 ± 10	60.85780 ± 24
1.2333605 ± 118	2.5111239 ± 169	4.2757066 ± 211	4.8607476 ± 289	2.1470320 ± 16	1.3820187 ± 45	4.8120542 ± 936	0.1424249 ± 2	0.5031909 ± 8	6.0189280 ±1051
1.0010127 ± 490	1.0005014 ± 321	1.0062877 ± 316	0.9999099 ± 218	1.0010181 ± 128	0.9987232 ± 182	1.0000361 ± 925	1.0000078 ± 5	0.9997372 ± 66	1.0039483 ± 888
71 Mar. 9 - 71 Sept. 9	73 Jan. 4 - 74 Feb. 19	72 June 9 - 74 Oct. 19	72 Nov. 15 - 74 Oct. 13	72 Oct. 31 - 74 Aug. 21	73 Feb. 28 - 73 Sept.22	73 July 4 - 75 Feb. 15	73 Jan. 28 - 74 Mar. 16	74 Feb. 14 - 74 Nov. 18	74 Nov. 12 - 76 Oct. 31

1975 II (46, 0".93)	1975 V (52, 1".57)	1975 VIII (119, 1".24)	1975 IX (296, 1".51)	1975 X (82, 1".64)	1975 XI (70, 1".44)	1975 XII (177, 1".46)	1975q (59, 1".77)	1975n (218, 1".92)	1976g (41, 1".81)
75 Jan. 28.0	75 Apr. 18.0	75 Aug. 16.0	75 Sept.25.0	75 Nov. 4.0	75 Dec. 14.0	75 Dec. 14.0	76 Jan. 23.0	76 Mar. 3.0	76 Oct. 29.0
75 Jan. 15.60301 ±3160	75 Apr. 4.57928 ± 140	75 Aug. 22.18135 ± 55	75 Sept. 5.33476 ± 4	75 Oct. 15.36017 ± 146	75 Dec. 21.18129 ± 7	75 Dec. 25.87745 ± 24	76 Jan. 3.92122 ± 160	76 Feb. 25.22158 ± 6	76 Nov. 3.15008 ± 374
193.43086 ± 387	264.12720 ± 122	261.36400 ± 10	116.97561 ± 7	152.02407 ± 174	358.09723 ± 24	246.24748 ± 13	215.47243 ± 140	358.41902 ± 9	193.25396 ± 261
22.08745 ± 37	157.21204 ± 18	11.67141 ± 5	295.65256 ± 2	216.10907 ± 3	270.61236 ± 30	277.98003 ± 8	280.79618 ± 78	118.23131 ± 10	80.72055 ± 104
112.02021 ± 30	55.25004 ± 15	50.64222 ± 5	80.77792 ± 10	118.23812 ± 79	70.62594 ± 19	91.60614 ± 6	93.95339 ± 121	43.07004 ± 14	38.80585 ± 41
6.8810770 ±1959	1.2169389 ± 88	3.0114563 ± 23	0.4255613 ± 5	0.8380474 ± 14	0.2187190 ± 11	1.6039330 ± 18	0.8639677 ± 19	0.1966260 ± 15	1.5688775 ± 487
1.0020356 ±1121	1.0014097 ± 334	0.9996011 ± 97	1.0000951 ± 16	0.9856534 ±1112	1.0000015 ± 75	0.9974502 ± 104	1.0012143 ±1446	0.9999712 ± 20	0.9996949 ± 929
76 Feb. 25 - 77 Feb. 25	75 Mar. 15 - 76 Mar. 7	74 Mar. 21 - 76 Nov. 21	75 July 6 - 75 Dec. 6	75 Oct. 6 - 76 Jan. 4	75 Nov. 13 - 76 Jan. 26	75 Oct. 6 - 76 Sept.20	75 Dec. 9 - 76 Feb. 4	75 Aug. 10 - 76 Sept.25	76 Apr. 27 - 76 Oct. 25

Note to Table I

For each entry, the first line gives the comet's designation, the number of observations utilized, and the mean residual of the orbit determination. Successive lines then give the epoch of osculation and time of perihelion passage (each in ephemeris time with only the last two digits of the year given); the argument of perihelion, longitude of the ascending node, and inclination (in degrees and referred to the ecliptic and mean equinox 1950.0); the perihelion distance (in AU); and the eccentricity. The errors are mean and are given in units of the last decimal place quoted. The last line gives the interval of time covered by the observations (the year again being restricted to its last two digits).

TABLE II. Quantities for establishing accuracy classes.

L,M,N	Mean error of $1/a$	Time span of observations	No. of planets for perturbations
8		48–96 months	
7		24–48	
6	1–4 units	12–24	
5	5–20	6–12	
4	21–100	3–6	
3	101–500	1.5–3	7–9
2	501–2500	0.75–1.5	3–6
1	2501–12 500	12–22 days	1–2
0	12 501–[a]	7–11	0
−1		3–6	
−2		1–2	

[a] Including parabolic orbits.

It appears that as many as 55% of the class I comets may be "new." Although the proportion rises above 80% for $q > 3.0$ AU, it remains surprisingly uniform at smaller values of q. Since the proportion of "new" comets is close to 50%, the mean $(1/a)_{orig}$ values for class I "new" comets in Table IV are close to the values in the "25%" column.

The results for the orbits of class II are singularly different from those of class I; if these were the only data available to Oort (1950), he would have been hard pressed to develop his concept of the cometary cloud at vast heliocentric distances. Larger mean errors of $1/a$ values of the class II orbits cannot by themselves account for the difference between the results for the two classes. The main feature of the class II distribution is that there are many more comets that must have passed near the Sun a number of times. This is seen as another consequence of the intrinsic fading of comets on their successive returns to the Sun. A fainter comet implies a shorter interval of observation and a tendency to disqualification from membership in class I.

These findings appear to be consistent with Whipple's (1977) recent conclusions on the brightness variations of comets. He has remarked that the brightness of older comets varies with the same power of heliocentric distance before and after perihelion (and "new" comets follow the same power law after perihelion passage), whereas "new" comets are often bright far from the Sun before perihelion (and brighten much more slowly), a circumstance that can lead to an early discovery and consequently class I status.

From the earlier tabulation of u_b and u_a values (Everhart and Raghavan 1970), it follows that the mean change $u_b + u_a$ in $1/a$ during one revolution of a comet around the Sun is close to zero. On the other hand, the mean change for the 50% of the comets whose orbits are made more elliptical is about 400 units. This average perturbation decreases somewhat with increasing q, and the lower limits for $(1/a)_{orig}$, shown in Table IV in the column labeled "old," are equal to five times this average perturbation. The number of "old" comets is also indicated.

TABLE III. Original and future orbits.

Comet	q	i	$u_b(p)$	$u_a(p)$	u_b	u_a	$(1/a)_{osc}$	$(1/a)_{orig}$	$(1/a)_{fut}$	
					Class I					
1965 VIII	0.008	141.9	- 235	+ 720	- 238	+ 722	+10891 ± 17	+11128	+11613	B
1962 III	0.031	65.0	- 131	+ 458	- 131	+ 458	- 105 ± 12	+ 25	+ 352	B
1973 XII	0.142	14.3	- 76	+ 601	- 75	+ 600	- 55 ± 3	+ 20	+ 545	A
1895 IV	0.192	141.6	- 89	+ 717	- 93	+ 722	- 265 ± 8	- 172	+ 457	B
1975n	0.197	43.1	-1423	- 117	-1423	- 117	+ 146 ± 10	+ 1569	+ 29	A
1853 III	0.307	61.5	- 832	+ 183	- 827	+ 179	- 815 ± 16	+ 12	- 636	B*
1957 III	0.316	119.9	- 680	+ 174	- 681	+ 175	- 779 ± 6	- 98	- 604	A
1899 I	0.327	146.3	- 985	- 159	- 984	- 160	- 1093 ± 9	- 109	- 1253	B
1903 IV	0.330	85.0	-1262	+ 228	-1263	+ 230	- 1230 ± 6	+ 33	- 1000	B
1957 V	0.355	93.9	- 211	+1293	- 212	+1293	+ 1789 ± 13	+ 2001	+ 3082	B
1941 I	0.368	49.9	-1317	- 253	-1320	- 251	- 1319 ± 10	+ 1	- 1570	B
1902 III	0.401	156.4	+ 54	+ 785	+ 52	+ 786	+ 79 ± 18	+ 27	+ 865	B*
1975 IX	0.426	80.8	-1043	+ 353	-1044	+ 354	- 223 ± 4	+ 821	+ 130	B
1969 IX	0.473	75.8	- 339	+ 262	- 337	+ 261	+ 170 ± 4	+ 507	+ 431	B
1886 II	0.479	84.4	- 825	+ 374	- 828	+ 378	- 496 ± 9	+ 332	- 118	B*
1911 V	0.489	33.8	- 157	+ 383	- 162	+ 388	+ 6118 ± 4	+ 6280	+ 6506	A
1964 VI	0.500	161.8	- 8	+1394	- 3	+1389	+ 8128 ± 15	+ 8131	+ 9517	B
1974 III	0.503	61.3	- 170	+ 184	- 168	+ 182	+ 522 ± 13	+ 690	+ 705	B
1907 IV	0.512	9.0	- 290	+ 961	- 295	+ 967	+ 2354 ± 7	+ 2650	+ 3322	A
1970 II	0.538	90.0	- 431	+ 239	- 427	+ 235	+ 6907 ± 5	+ 7334	+ 7142	B
1947 IV	0.560	39.3	-1327	- 33	-1328	- 32	+ 4596 ± 12	+ 5924	+ 4564	B
1858 VI	0.578	117.0	+ 38	+ 505	+ 35	+ 508	+ 6405 ± 14	+ 6370	+ 6913	B*
1963 I	0.632	160.6	- 909	+ 12	- 912	+ 14	+10477 ± 3	+11389	+10492	A
1886 I	0.642	82.6	- 691	+ 437	- 690	+ 436	- 708 ± 8	- 18	- 272	B
1886 IX	0.663	101.6	- 661	+ 626	- 661	+ 625	- 615 ± 19	+ 46	+ 11	B
1888 I	0.699	42.3	- 743	+ 386	- 744	+ 386	+ 5904 ± 11	+ 6648	+ 6290	B
1912 II	0.716	79.8	- 675	+ 267	- 675	+ 267	- 630 ± 6	+ 45	- 363	B
1952 I	0.740	152.5	- 997	+ 218	- 995	+ 216	+ 353 ± 7	+ 1348	+ 569	B
1948 I	0.748	140.6	- 508	+ 118	- 509	+ 119	- 485 ± 4	+ 24	- 366	A
1953 II	0.778	97.2	- 317	+ 159	- 317	+ 159	- 442 ± 9	- 125	- 283	B
1911 VI	0.788	108.1	- 160	+ 429	- 164	+ 433	+ 2327 ± 16	+ 2491	+ 2761	B
1941 IV	0.790	168.2	- 894	- 5	- 892	- 7	+ 1136 ± 16	+ 2029	+ 1130	B
1861 II	0.822	85.4	-1530	+ 96	-1521	+ 87	+18155 ± 11	+19676	+18242	B*
1941 VIII	0.875	94.5	- 356	+ 468	- 356	+ 468	- 278 ± 7	+ 78	+ 190	B*
1908 III	0.945	140.2	- 891	+ 324	- 884	+ 318	- 711 ± 7	+ 174	- 393	B
1954 X	0.970	53.2	- 919	- 117	- 918	- 117	- 848 ± 25	+ 70	- 965	B
1892 VI	0.976	24.8	- 418	- 93	- 425	- 87	- 452 ± 11	- 27	- 539	B
1915 II	1.005	54.8	- 383	+1269	- 385	+1270	- 310 ± 5	+ 75	+ 960	A
1921 II	1.008	132.2	- 376	+ 7	- 372	+ 3	- 354 ± 11	+ 18	- 351	B
1953 III	1.022	93.9	- 431	+ 663	- 431	+ 663	+ 2552 ± 9	+ 2983	+ 3215	B
1892 I	1.027	38.7	+ 49	+ 521	+ 49	+ 520	+ 1236 ± 14	+ 1187	+ 1756	B
1931 III	1.047	42.3	-1158	+ 266	-1155	+ 263	+19865 ± 19	+21020	+20128	B
1897 I	1.063	146.1	- 929	+ 125	- 930	+ 126	- 925 ± 17	+ 5	- 799	B
1898 I	1.095	72.5	- 629	- 173	- 629	- 173	+17846 ± 34	+18475	+17673	B
1914 V	1.104	68.0	- 168	+ 202	- 169	+ 203	- 140 ± 2	+ 29	+ 63	A
1925 I	1.109	100.0	- 584	+ 12	- 585	+ 12	- 545 ± 11	+ 40	- 533	A
1970 XV	1.113	126.7	- 326	+ 258	- 326	+ 259	- 43 ± 2	+ 283	+ 215	A
1946 VI	1.136	57.0	- 727	+ 699	- 728	+ 699	- 683 ± 4	+ 44	+ 16	A
1975 V	1.217	55.3	-1185	+ 322	-1181	+ 318	- 1158 ± 27	+ 23	- 841	B
1959 IX	1.253	19.6	+ 130	+2376	+ 132	+2374	+ 201 ± 14	+ 69	+ 2575	B
1964 IX	1.259	68.0	+ 45	+ 876	+ 48	+ 872	+ 2769 ± 15	+ 2721	+ 3641	B
1958 III	1.323	15.8	- 207	+1750	- 212	+1755	+ 43 ± 14	+ 256	+ 1798	B
1900 I	1.332	146.4	- 846	+ 67	- 852	+ 73	- 795 ± 30	+ 57	- 722	B
1943 I	1.354	19.7	-1585	+ 380	-1567	+ 381	+ 5765 ± 6	+ 7352	+ 6146	B
1973 VII	1.382	121.6	- 617	+1166	- 617	+1166	+ 924 ± 13	+ 1541	+ 2090	B
1942 IV	1.445	79.4	- 634	- 203	- 634	- 203	- 618 ± 5	+ 16	- 821	B*
1948 II	1.500	77.5	- 752	+ 777	- 751	+ 776	- 724 ± 8	+ 28	+ 53	B
1888 V	1.528	56.3	- 57	+ 216	- 55	+ 215	+ 5571 ± 34	+ 5626	+ 5786	B
1925 VII	1.566	49.3	- 260	- 86	- 268	- 78	- 244 ± 12	+ 24	- 322	A
1975 XII	1.604	91.6	- 375	- 43	- 374	- 45	+ 1590 ± 6	+ 1964	+ 1545	B
1959 I	1.628	61.3	+ 6	+ 162	+ 6	+ 162	+ 82 ± 6	+ 76	+ 244	A
1925 III	1.633	27.0	- 789	+1531	- 788	+1530	+ 2990 ± 8	+ 3778	+ 4521	B*
1932 VII	1.647	78.4	- 306	+ 36	- 309	+ 39	- 365 ± 15	- 56	- 327	B
1953 I	1.665	59.1	- 830	+ 876	- 820	+ 866	+ 2457 ± 6	+ 3277	+ 3323	B
1917 III	1.686	25.7	+ 334	+ 412	+ 336	+ 410	+ 353 ± 3	+ 17	+ 763	A
1968 I	1.697	129.3	- 339	+ 201	- 342	+ 204	+ 500 ± 7	+ 842	+ 704	A
1898 VII	1.702	69.9	- 618	- 159	- 617	- 159	- 549 ± 7	+ 68	- 709	A
1970 III	1.719	86.3	- 47	+ 388	- 46	+ 387	+ 509 ± 4	+ 555	+ 896	A
1946 I	1.724	72.8	- 665	+1051	- 665	+1051	- 678 ± 3	- 13	+ 373	A
1937 IV	1.734	41.6	- 135	+1473	- 141	+1479	- 79 ± 8	+ 62	+ 1400	B
1889 I	1.815	166.4	- 726	+ 106	- 725	+ 105	- 677 ± 3	+ 48	- 573	A
1890 II	1.908	120.6	- 229	+ 265	- 229	+ 265	- 139 ± 10	+ 89	+ 126	B*
1910 IV	1.948	121.1	- 371	+ 185	- 370	+ 184	+ 104 ± 11	+ 474	+ 288	B
1892 II	1.971	89.7	-1033	+ 699	-1034	+ 701	- 188 ± 14	+ 846	+ 513	B
1907 I	2.052	141.7	- 531	+ 216	- 514	+ 199	- 489 ± 19	+ 25	- 290	B
1949 IV	2.058	105.8	- 81	+ 303	- 76	+ 298	+ 659 ± 7	+ 735	+ 957	B*
1930 IV	2.079	72.0	- 773	+ 205	- 776	+ 208	- 252 ± 13	+ 524	- 44	B*
1948 V	2.107	92.9	- 406	+ 403	- 407	+ 404	- 373 ± 4	+ 34	+ 31	A
1962 VIII	2.133	153.3	- 42	+ 510	- 46	+ 514	+ 4889 ± 1	+ 4935	+ 5403	A
1973 II	2.147	141.9	- 792	+ 444	- 794	+ 446	- 474 ± 6	+ 320	- 28	A
1944 IV	2.226	95.0	- 956	+ 417	- 954	+ 415	- 937 ± 13	+ 18	- 522	A
1889 II	2.256	163.8	- 851	+1185	- 852	+1187	+ 81 ± 30	+ 933	+ 1268	B
1922 II	2.259	51.5	- 354	- 190	- 355	- 188	- 334 ± 9	+ 21	- 523	B
1898 VIII	2.285	22.5	+ 286	+ 405	+ 267	+ 404	- 216 ± 36	- 71	+ 620	B
1932 VI	2.314	125.0	- 664	+ 379	- 664	+ 378	- 619 ± 3	+ 45	- 240	A
1947 I	2.408	108.2	- 390	+ 418	- 392	+ 420	- 393 ± 5	- 1	+ 26	A
1945 I	2.411	17.3	- 366	- 306	- 362	- 311	+ 2696 ± 27	+ 3058	+ 2385	B
1972 VIII	2.511	138.6	- 248	+ 561	- 249	+ 562	- 200 ± 13	+ 49	+ 362	A
1949 I	2.517	130.3	- 244	+ 327	- 241	+ 324	+ 257 ± 5	+ 498	+ 581	A
1950 I	2.553	131.4	- 539	+ 813	- 542	+ 817	- 279 ± 5	+ 263	+ 537	A
1951 I	2.572	144.2	- 509	+ 742	- 516	+ 749	- 479 ± 4	+ 37	+ 270	A
1904 I	2.708	125.1	- 719	+1006	- 723	+1011	- 496 ± 3	+ 227	+ 515	A
1903 II	2.774	43.9	- 243	- 271	- 244	- 270	- 218 ± 9	+ 26	- 488	B
1947 VI	2.828	97.3	- 606	+ 139	- 606	+ 139	- 372 ± 9	+ 234	- 233	A
1975 VIII	3.011	50.6	+ 100	+ 381	+ 96	+ 385	+ 132 ± 3	+ 36	+ 517	A
1947 VIII	3.261	155.1	- 733	+ 924	- 732	+ 923	- 699 ± 10	+ 34	+ 225	A
1905 IV	3.340	4.3	- 486	- 61	- 480	- 67	- 452 ± 8	+ 28	- 519	B*
1927 IV	3.684	87.7	- 128	+ 592	- 128	+ 592	+ 494 ± 3	+ 623	+ 1087	A
1914 III	3.747	71.0	- 904	+ 876	- 905	+ 877	- 878 ± 20	+ 27	- 1	A
1955 VI	3.870	100.4	- 177	+ 387	- 174	+ 383	- 132 ± 3	+ 42	+ 252	A
1936 I	4.043	66.1	- 525	+ 226	- 524	+ 225	- 506 ± 6	+ 19	- 281	A
1956 I	4.077	79.6	-1186	+ 919	-1184	+ 917	- 1145 ± 3	+ 39	- 228	A
1925 VI	4.181	146.7	- 617	+ 710	- 617	+ 710	- 582 ± 9	+ 35	+ 128	A
1959 X	4.267	125.5	- 250	+ 208	- 247	+ 205	- 207 ± 11	+ 40	- 2	B
1972 IX	4.276	79.4	-1540	+ 867	-1540	+ 867	- 1471 ± 7	+ 69	- 603	A
1957 VI	4.447	33.2	- 633	+ 764	- 634	+ 766	- 617 ± 5	+ 17	+ 148	A
1954 V	4.496	123.9	- 708	+ 605	- 702	+ 600	- 621 ± 16	+ 82	- 21	A
1973 X	4.812	137.4	- 540	+ 517	- 543	+ 520	- 7 ± 19	+ 536	+ 512	A
1972 XII	4.861	113.1	- 462	+ 341	- 458	+ 337	+ 19 ± 4	+ 476	+ 356	A
1974 XII	6.019	60.9	- 668	+1225	- 667	+1225	- 656 ± 15	+ 11	+ 569	A
1975 II	6.881	112.0	- 365	+ 362	- 364	+ 361	- 296 ± 16	+ 68	+ 65	A
					Class II					
1963 V	0.005	144 6	+ 7	+1019	+ 9	+1017	+10705 ± 141	+10697	+11722	A
1882 II	0.008	142.0	- 239	+ 765	- 242	+ 768	+12023 ± 271	+12265	+12791	B*
1961 V	0.040	24.2	+ 145	+1320	+ 148	+1317	+ 2357 ± 269	+ 2209	+ 3674	B*
1847 I	0.043	48.7	- 315	+ 535	- 317	+ 536	+ 2122 ± 79	+ 2438	+ 2658	B*
1882 I	0.061	73.8	- 54	+ 689	- 53	+ 688	+ 92 ± 20	+ 144	+ 779	A*
1910 I	0.129	138.8	- 95	+ 633	- 96	+ 634	+ 40 ± 100	+ 135	+ 674	A*
1948 XI	0.135	23.1	- 814	+ 38	- 814	+ 38	+ 480 ± 32	+ 1294	+ 518	A*
1927 IX	0.176	85.1	- 766	- 1	- 765	- 2	+ 909 ± 89	+ 1674	+ 907	A
1948 IV	0.208	23.2	+ 80	+1332	+ 79	+1333	+ 604 ± 176	+ 525	+ 1937	B*
1975 XI	0.219	70.6	+ 47	+1226	+ 49	+1224	- 7 ± 34	- 56	+ 1218	A
1844 III	0.251	45.6	+ 197	+1289	+ 196	+1291	+ 2785 ± 301	+ 2589	+ 4075	B
1886 V	0.270	87.7	- 294	- 49	- 291	- 52	+11923 ± 87	+12213	+11870	A
1911 IV	0.303	96.5	- 409	+ 658	- 409	+ 658	- 483 ± 47	- 74	+ 175	A
1847 VI	0.329	108.1	- 737	+ 623	- 735	+ 621	- 523 ± 81	+ 212	+ 98	B*
1873 V	0.385	121.5	- 619	+ 102	- 617	+ 100	+ 703 ± 185	+ 1320	+ 803	B*
1903 I	0.411	30.9	- 255	+ 221	- 259	+ 226	+ 804 ± 250	+ 1063	+ 1030	B*
1967 II	0.419	9.1	- 986	+ 48	- 982	+ 43	- 932 ± 38	+ 49	- 889	A
1930 III	0.482	67.1	- 757	+ 15	- 757	+ 15	+16202 ± 30	+16959	+16217	A*
1960 II	0.504	159.6	- 463	+ 11	- 454	+ 2	- 590 ± 23	- 135	- 587	A
1936 III	0.518	121.9	- 180	+ 502	- 184	+ 505	+10823 ± 80	+11007	+11329	B*
1955 III	0.534	86.5	- 110	+ 969	- 105	+ 965	+19907 ± 81	+20013	+20872	A
1863 III	0.629	85.5	- 613	- 75	- 618	- 70	+ 1465 ± 141	+ 2083	+ 1395	B*
1893 II	0.675	160.0	- 191	+ 995	- 187	+ 991	+ 800 ± 100	+ 987	+ 1791	A*
1874 III	0.676	66.3	-1455	+ 62	-1460	+ 68	+ 1746 ± 300	+ 3206	+ 1814	A*
1954 VIII	0.677	116.2	- 490	+ 224	- 471	+ 205	- 422 ± 40	+ 49	+ 217	A
1961 VIII	0.681	155.7	-1644	+ 640	-1634	+ 630	+12021 ± 31	+13656	+12651	A
1911 II	0.684	148.4	- 924	+ 723	- 921	+ 720	+ 5416 ± 64	+ 6337	+ 6136	A
1871 IV	0.691	98.3	- 387	+ 760	- 378	+ 752	+ 6200 ± 233	+ 6579	+ 6952	B*
1914 IV	0.713	77.8	- 366	+ 909	- 367	+ 910	+ 1872 ± 299	+ 2239	+ 2782	B
1939 I	0.716	63.5	- 975	- 121	- 978	- 118	+ 6835 ± 300	+ 7813	+ 6716	B*
1881 III	0.735	63.4	+ 47	+ 806	+ 58	+ 795	+ 5519 ± 70	+ 5461	+ 6314	A*
1954 XII	0.746	88.5	- 269	+ 292	- 269	+ 292	- 233 ± 33	+ 36	+ 59	A*
1863 I	0.795	85.4	- 580	+ 830	- 583	+ 833	- 62 ± 60	+ 521	+ 771	A*
1935 I	0.811	65.4	- 53	+ 665	- 54	+ 666	+10721 ± 40	+10774	+11387	A*
1964 VIII	0.822	171.9	+ 11	+ 551	+ 26	+ 537	+18688 ± 535	+18662	+19224	B
1975 X	0.838	118.2	- 423	+ 265	- 459	+ 301	+17119 ± 133	+17578	+17420	B
1826 IV	0.853	25.9	+ 189	- 49	+ 192	- 51	+ 2941 ± 600	+ 2749	+ 2890	B*
1844 II	0.855	131.4	- 537	+1035	- 540	+1039	+ 267 ± 200	+ 807	+ 1306	A*
1937 V	0.863	146.4	- 107	+ 264	- 107	+ 264	+ 17 ± 29	+ 124	+ 281	A
1975q	0.864	94.0	- 676	- 52	- 672	- 56	- 1405 ± 167	- 734	- 1461	B
1955 V	0.885	107.5	- 345	+ 640	- 343	+ 639	- 1071 ± 121	- 727	- 432	A
1861 I	0.921	79.8	- 809	- 187	- 811	- 185	+17959 ± 40	+18770	+17775	B*
1864 III	0.931	109.7	- 367	+ 616	- 366	+ 615	+ 690 ± 56	+ 1056	+ 1305	A*
1894 II	0.983	87.0	- 920	+ 174	- 915	+ 169	+10291 ± 493	+11206	+10459	B*
1877 III	1.009	77.2	- 18	+ 365	- 15	+ 363	+ 2059 ± 169	+ 2074	+ 2422	B*
1900 II	1.015	62.5	-1019	- 157	-1014	- 161	- 404 ± 105	+ 610	- 565	B*
1811 I	1.035	106.9	- 393	+ 124	- 395	+ 125	+ 4708 ± 36	+ 5103	+ 4833	A*
1932 V	1.037	71.7	- 165	- 6	- 161	- 10	+22784 ± 129	+22945	+22774	B*
1889 IV	1.040	66.0	- 604	+ 554	- 602	+ 551	+ 2298 ± 130	+ 2899	+ 2849	A
1961 II	1.062	151.0	- 962	+ 122	- 966	+ 126	+ 9514 ± 34	+10480	+ 9640	A
1940 III	1.062	133.1	-1248	+ 248	-1250	+ 251	- 1374 ± 316	- 124	- 1123	B
1850 I	1.081	68.2	- 860	+ 58	- 860	+ 58	+ 1296 ± 200	+ 2155	+ 1353	A*
1940 IV	1.082	54.7	- 392	+1394	- 392	+1394	+17701 ± 35	+18093	+19095	A
1936 II	1.100	78.5	- 815	+ 444	- 815	+ 444	+ 7478 ± 42	+ 8294	+ 7923	A*
1919 V	1.115	46.4	- 218	+ 157	- 219	+ 157	- 199 ± 33	+ 20	- 42	A
1932 X	1.131	24.5	- 145	+ 244	- 142	+ 242	+24420 ± 500	+24562	+24661	B*
1822 IV	1.145	127.3	- 263	+ 914	- 265	+ 916	+ 3217 ± 872	+ 3481	+ 4133	B*
1920 III	1.148	22.0	+ 128	+1744	+ 133	+1739	+ 5157 ± 112	+ 5023	+ 6896	B
1959 IV	1.150	48.3	-1393	+ 324	-1392	+ 323	- 799 ± 43	+ 593	+ 476	A*
1849 II	1.159	67.2	- 784	- 212	- 786	- 210	- 811 ± 38	- 25	- 1021	A*
1968 VI	1.160	143.2	- 490	+ 831	- 491	+ 833	- 573 ± 116	- 82	+ 260	A
1914 II	1.199	23.9	- 219	+1653	- 215	+1649	- 88 ± 27	+ 126	+ 1561	A
1952 VI	1.202	45.6	+ 71	+ 337	+ 69	+ 339	+ 71 ± 48	+ 2	+ 410	A*
1840 II	1.220	120.8	- 190	+ 613	- 182	+ 606	+ 5530 ± 1429	+ 5713	+ 6136	B*
1971 V	1.233	109.7	- 683	+ 337	- 679	+ 333	- 821 ± 40	- 142	- 488	A
1825 IV	1.241	146.4	- 803	+1261	- 805	+1263	+ 3682 ± 50	+ 4488	+ 4946	A*
1959 III	1.251	12.8	-1696	+ 186	-1696	+ 186	- 2142 ± 524	- 446	- 1956	B*
1932 I	1.254	74.3	- 956	+ 510	- 955	+ 509	+22220 ± 394	+23175	+22729	B*
1890 VI	1.260	98.9	- 270	+ 637	- 271	+ 638	+ 645 ± 118	+ 916	+ 1283	B*
1948 X	1.273	87.6	- 667	+ 336	- 668	+ 338	+ 1964 ± 252	+ 2633	+ 2302	A
1905 VI	1.296	126.4	- 780	+ 513	- 780	+ 513	- 151 ± 50	+ 630	+ 363	B*
1863 VI	1.313	83.3	- 519	+1276	- 521	+1277	- 507 ± 50	+ 14	+ 770	A*
1926 I	1.345	128.3	- 147	+ 666	- 148	+ 666	+ 5660 ± 1204	+ 5808	+ 6326	B*
1887 IV	1.394	17.6	-1473	+ 172	-1473	+ 172	+ 2803 ± 138	+ 4276	+ 2975	B*
1955 IV	1.427	50.0	- 262	+ 163	- 267	+ 167	+ 4086 ± 46	+ 4353	+ 4254	A*
1840 IV	1.480	57.9	- 159	- 57	- 168	- 49	+23014 ± 1200	+23181	+22965	B*
1963 III	1.537	86.2	- 18	+ 461	- 19	+ 463	+ 1262 ± 56	+ 1281	+ 1725	A*
1976g	1.569	38.8	+ 152	+ 373	+ 150	+ 376	+ 194 ± 59	+ 45	+ 570	A
1887 II	1.630	104.3	0	+ 614	- 1	+ 615	+10003 ± 156	+10004	+10618	B*
1924 I	1.756	72.3	- 279	- 95	- 277	- 96	+ 798 ± 130	+ 1076	+ 703	A
1847 III	1.766	96.6	- 805	+1061	- 805	+1061	+ 799 ± 85	+ 1604	+ 1860	A*
1880 II	1.814	123.1	- 978	+ 341	- 982	+ 345	- 448 ± 392	+ 534	- 103	B*
1904 II	1.882	99.6	- 292	+ 536	- 285	+ 530	- 360 ± 98	- 75	+ 170	A
1936 V	1.954	11.6	- 553	+1650	- 547	+1644	+14077 ± 433	+14623	+15721	B*
1966 II	2.019	28.7	+ 256	+ 458	+ 257	+ 458	+ 900 ± 73	+ 643	+ 1358	A
1847 II	2.116	100.4	- 523	- 110	- 522	- 111	- 342 ± 400	+ 180	- 453	A*
1966 V	2.385	40.3	+ 183	+ 330	+ 183	+ 329	+ 262 ± 46	+ 78	+ 591	A
1971 I	3.277	175.6	- 644	+ 373	- 649	+ 378	+ 933 ± 139	+ 1582	+ 1311	A
1969 I	3.316	45.2	- 86	+ 184	- 85	+ 184	+ 1417 ± 27	+ 1502	+ 1601	A

Note to Table III

For each entry are given the perihelion distance q (in AU) and the inclination i (in degrees and referred to the ecliptic and mean equinox 1950.0). The quantities $u_b = (1/a)_{osc} - (1/a)_{orig}$ and $u_a = (1/a)_{fut} - (1/a)_{osc}$ are supplied both with respect to perihelion (p) and with respect to the 40-day date closest to the time of perihelion passage; then come $(1/a)_{osc}$ (with respect to this 40-day date) and its mean error, and the resulting $(1/a)_{orig}$ and $(1/a)_{fut}$; all these numbers are in units of 10^{-6} SU^{-1}. The orbits are listed according to increasing q and separated into classes I and II, the last columns denoting the further subdivisions of these classes; an asterisk (*) identifies those orbits not calculated or recalculated as part of this program.

TABLE IV. Statistics of original orbits.

q (AU)	Average $(1/a)_{orig}$ (units) 25%	50%	75%	"New"	"Old"	Number of comets "New"	"Old"	Total
				Class I				
<0.5	−37	+221	+2834	−29	>2700	9	2	16
0.5–1.0	+155	+1930	+6982	+12	>2450	8	9	21
1.0–1.5	+36	+446	+5880	+38	>2200	10	5	19
1.5–2.0	+31	+296	+1939	+37	>1900	10	4	18
2.0–3.0	+18	+173	+1173	+18	>1550	10	2	20
>3.0	+27	+43	+230	+39	>850	14	0	17
Total	+15	+236	+3324	+21	...	61	22	111
				Class II				
<0.5	+366	+1345	+6929	−27	>2700	3	4	18
0.5–1.0	+697	+4297	+11620	−302	>2450	5	14	26
1.0–1.5	+578	+2836	+10742	−98	>2200	8	17	32
1.5–2.0	+395	+1124	+6878	−15	>1900	2	2	8
>2.0	+232	+762	+1362	+78	>980	1	0	5
Total	+404	+2314	+9476	−122	...	19	37	89

Cometary fading apparently is also responsible for the complete absence of "old" comets with $q > 2$ AU in class II and their virtual absence in class I. Consequently the spread in $(1/a)_{orig}$ is considerably larger for comets with $q < 2$ AU, and it is largest and the proportion of "old" comets greatest when $0.5 < q < 1.5$ AU. Of the six "old" comets having $q < 0.5$ AU, three are members of the Kreutz Sun-grazing group and are thus highly selective objects. One can speculate that the relative paucity of "old" comets of $q < 0.5$ AU can be attributed to the rapid dissolution or disintegration of comets that pass so close to the Sun, although selection effects in the discovery rates might also be involved.

Let us estimate the average number of returns made by the "old" comets. If we compare Monte Carlo exact orbit integrations, which were used to trace the average period of observable long-period comets as a function of the number of returns (Everhart 1976, Fig. 3, curve B), with the mean revolution period for the "old" comets in Table III, we find that they have completed, on the average, only 30 and 70 returns of classes I and II, respectively. We may conclude, therefore, that really old comets (by number of revolutions, not by years!) are relatively rare. Again, the observability of such "wornout" comets obviously is a factor.

The fact that the mean $(1/a)_{orig}$ of "new" comets tends to be negative at small q is presumably due to the influence of nongravitational forces. In order to gain greater insight into the variation of the original semimajor axes of gravitational orbits with perihelion distance, we grouped the "new" class I comets into a number of overlapping intervals in q. The interval lengths were wider for greater q. Averaging $(1/a)_{orig}$ in each group and plotting it versus $1/q$, we obtained the result shown in Fig. 1. The relation is remarkably linear, satisfying an empirical fit:

$$\langle(1/a)_{orig}\rangle = +46.3 - 23.7\ (1/q) \text{ units.}$$
$$\pm 1.3 \quad \pm 0.6 \text{ (m.e.)} \qquad (2)$$

The dip between $q = 2$ and 3 AU is much less conspicuous than in Table IV, because the effect of comet 1898 VIII, to which it is due, has now been suppressed more appreciably. The scatter in $(1/a)_{orig}$, corrected for the scatter in $1/q$, is plotted versus $1/q$ in Fig. 2. It increases steeply with $1/q$ for $q > 0.7$ AU and much more slowly at smaller q.

Equation (2) quantitatively demonstrates that neglect of the nongravitational effects does indeed result, on the average, in seemingly more hyperbolic orbits; a comet from the Oort cloud with $q \simeq 0.5$ AU is equally likely to have an elliptical or hyperbolic original orbit as determined from a purely gravitational solution.

The existence of many more class II negative $(1/a)_{orig}$ values might suggest that, on the average, these comets have been subjected to much larger nongravitational forces. We have already discussed (Marsden, Sekanina,

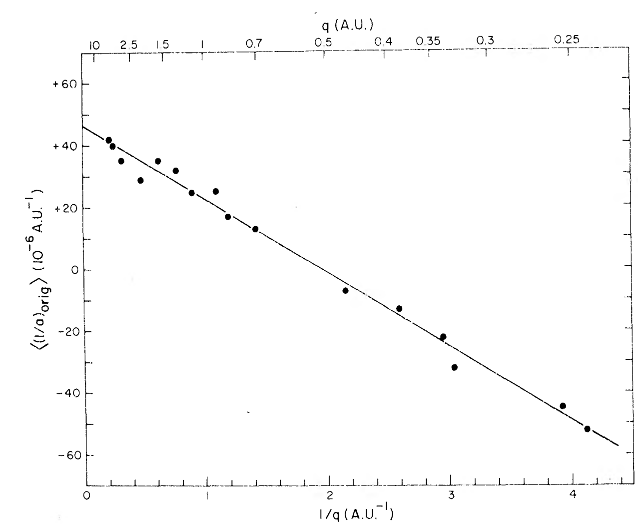

FIG. 1. Average $(1/a)_{orig}$ for 16 overlapping groups of "new" class I comets versus the average $1/q$. The straight line is a least-squares fit through the points.

TABLE V. Nongravitational orbital elements.

1886 I (142, 2".04)	1915 II (217, 1".99)	1954 X (82, 1".19)
86 Apr. 4.0	15 July 2.0	54 June 27.0
86 Apr. 6.45424 ± 32	15 July 17.65227 ± 18	54 July 7.34922 ± 33
126.58335 ± 37	247.77673 ± 15	194.38169 ± 46
37.26520 ± 6	72.75884 ± 4	2.33498 ± 23
82.62383 ± 26	54.79083 ± 12	53.22244 ± 6
0.6423629 ± 30	1.0052865 ± 18	0.9701164 ± 44
1.0002715 ± 73	1.0001507 ± 103	1.0005640 ± 206
85 Dec. 2 - 86 July 20	15 Feb. 16 - 16 Sept.26	53 Oct. 16 - 54 Sept.15
+ 2.6 ± 0.2	+ 2.8 ± 0.1	+ 5.9 ± 0.3
- 0.2 ± 0.1	+ 0.2 ± 0.1	- 0.3 ± 0.2

1957 III (150, 1".37)	1960 II (37, 1".40)	1970 II (391, 1".28)
57 Mar. 23.0	60 Mar. 7.0	70 Apr. 4.0
57 Apr. 8.03240 ± 10	60 Mar. 20.99560 ± 37	70 Mar. 20.04460 ± 8
308.78521 ± 49	306.65249 ± 122	354.15097 ± 25
215.15965 ± 8	251.95722 ± 45	223.95888 ± 19
119.94930 ± 6	159.60169 ± 17	90.04366 ± 4
0.3160354 ± 28	0.5043527 ± 49	0.5376065 ± 7
1.0001678 ± 61	1.0001452 ± 166	0.9961925 ± 101
56 Nov. 8 - 58 Apr. 11	60 Jan. 4 - 60 June 17	69 Dec. 30 - 70 Oct. 27
+ 1.7 ± 0.2	+ 5.9 ± 0.3	+ 1.9 ± 0.1
+ 0.1 ± 0.0	- 1.4 ± 0.2	+ 0.1 ± 0.1

1971 V (131, 1".32)	1974 III (159, 1".23)
71 Mar. 30.0	74 Mar. 14.0
71 Apr. 17.24973 ± 129	74 Mar. 18.35634 ± 7
152.35621 ± 125	333.13024 ± 20
103.37527 ± 29	143.03795 ± 33
109.68459 ± 33	61.28976 ± 9
1.2332924 ± 108	0.5031906 ± 6
1.0007747 ± 529	0.9996972 ± 255
71 Mar. 9 - 71 Sept. 9	74 Feb. 14 - 74 Nov. 18
+ 5.6 ± 0.4	+ 0.9 ± 0.2
- 1.6 ± 0.5	- 0.4 ± 0.2

Note to Table V

This table is in the same format as Table I, except that the last two lines under each entry give the radial and transverse nongravitational parameters A_1 and A_2, described by Marsden, Sekanina, and Yeomans (1973), adopting a scaling distance r_0 of 2.808 AU.

and Yeomans 1973) the likelihood that nongravitational forces were acting on two of these comets (1960 II and 1971 V). Comet 1944 I is not listed here, but that object, observed for only a short while and only because of its proximity to Earth, might have been subject to extremely large nongravitational forces (Marsden, Sekanina, and Yeomans 1973). Since these forces presumably represent *relative* mass loss, 1944 I must have been a very small comet. According to Vsekhsvyatskij (1958) the total

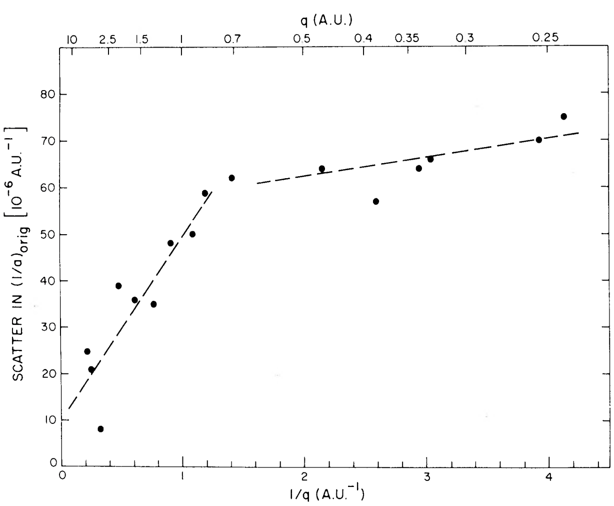

FIG. 2. Scatter in $(1/a)_{orig}$ for the 16 groups of "new" class I comets of Fig. 1, corrected for the scatter in $1/q$, versus $1/q$.

absolute magnitude of this comet was $H_{10} = 10.7$, putting it among the intrinsically faintest (and presumably least massive) 5% of all known nearly parabolic comets. Similarly, comets 1975q [with the largest negative $(1/a)_{orig}$ in Table III] and 1959 III both had $H_{10} \gtrsim 10$ (Marsden 1975b; Vsekhsvyatskij 1966), whereas the orbit interpretation for the remaining comet having $(1/a)_{orig}$ more negative than −200 units (i.e., 1955 V) is complicated by the splitting of this object.

TABLE VI. Further nongravitational solutions.

Comet	A_1	Mean residual	$(1/a)_{orig}$ (units)	Note
1899 I	+2.9 ± 0.4	1".72	−46 ± 91	Comet split
1946 I	+3.0	1.28	−5	A_1 assumed
1948 I	+0.8 ± 0.2	1.78	+47 ± 18	
1953 II	+5.0	1.16	+86	A_1 assumed
1955 V	+1.5 ± 0.8	1.79	−284 ± 289	Comet split
1975 XI	+0.8 ± 0.5	1.44	−154 ± 889	
1975q	+0.5 ± 0.1	1.73	+158 ± 378	

VI. NONGRAVITATIONAL ORBIT SOLUTIONS

We have already remarked that all the orbits listed in Table I are from gravitational solutions. For four of the comets (1957 III, 1960 II, 1970 II, and 1971 V) we previously also made nongravitational solutions, demonstrating that one need not accept the three apparently negative $(1/a)_{orig}$ values (Marsden, Sekanina, and Yeomans 1973). These nongravitational orbits (which have in any case recently been improved) are listed for reference in Table V, together with nongravitational orbits for four other comets—1886 I, 1915 II, 1954 X, and 1974 III—where these solutions caused insignificant improvements in the residuals. Comet 1915 II is another comet that split, and 1886 I is a further case where the negative $(1/a)_{orig}$ of the gravitational solution can obviously be disregarded. A slightly different solution for comet 1886 I in which the transverse component A_2 of the nongravitational force is assumed to be exactly zero yields [with the help of Eqs. (21) and (24) of Marsden, Sekanina, and Yeomans (1973)] a value of $(1/a)_{orig} = +76 \pm 10$ units. Svedstrup (1905) also suggested that comet 1886 I was influenced by nongravitational forces, although Redlich (1911) did not agree.

Nongravitational solutions have also been attempted for some of the other comets listed in Table I, but the results were either indeterminate or did not yield any significant improvement in the residuals. These results are summarized in Table VI. In all these computations A_2 was assumed to be equal to zero. Whenever a solution was actually made for A_1, this quantity turned out to be positive. Only for comet 1975 XI has $(1/a)_{orig}$ become more negative, but the change is completely masked by the large increase in mean error.

Even if we assume a rather large value of A_1 (which would not be expected for a comet of $q \gtrsim 1.5$ AU), we find that $(1/a)_{orig}$ for comet 1946 I remains slightly negative. This orbit is very well determined, and the comet was relatively bright intrinsically and was not observed to experience any problems such as splitting. As for the negative $(1/a)_{orig}$ values for comets of even larger q, we remarked earlier (Marsden and Sekanina 1973) on the uncertainty of the orbits of comets 1898 VIII and 1947 I, while an alternative solution for the class II comet 1904 II ($q = 1.88$ AU), satisfying 52 observations with a mean residual 1.″83, yields $(1/a)_{orig} = -33 \pm 105$ units.

VII. CONCLUDING REMARKS

The calculations presented here fully confirm the general correctness of Oort's (1950) conclusions that a large number of the nearly parabolic comets are observed on their first approaches to the Sun and that fading tends to prevent comets from being rediscovered on their subsequent returns. The increased sample of high-quality orbits reenforces our previous conclusion (Marsden and Sekanina 1973) that the Oort effect is very striking for comets of large q, and it allows us to estimate quantitatively the influence of nongravitational forces on the orbits of nearly parabolic comets of smaller q. There is also circumstantial evidence that intrinsic fading is particularly significant for comets of very small q.

Some differences are evident between the results for the orbits of class I and class II accuracy. While a semiquantitative explanation for these has been suggested, it is at the same time desirable to augment the sample of class I orbits. The improved data available in recent years for comets of large q are very encouraging, but in the future efforts should be made to obtain extended arcs of observation for all nearly parabolic comets.

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