

NEW ORIGINAL AND FUTURE COMETARY ORBITS

EDGAR EVERHART

Chamberlin Observatory and Physics Department, University of Denver, Denver, Colorado 80208

BRIAN G. MARSDEN

Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138

Received 26 July 1982

ABSTRACT

Values of "original" and "future" reciprocal semimajor axes are calculated for 28 new osculating cometary orbits derived during the past few years. Values of planetary perturbations are also provided for 16 comets for which accurate osculating orbits are not yet available. No convincing evidence is found for original hyperbolic orbits.

This paper updates that of Marsden, Sekanina, and Everhart (1978, hereinafter called Paper I), which provided 200 original and future orbits of long-period comets. Specifically, we are concerned with the reciprocal semimajor axes of the comets' orbits (in units of 10^{-6} AU $^{-1}$) referred to the barycenter of the solar system, and determined when the comet is over 60 AU from the Sun. A positive $1/a$ value in the past indicates that the comet was originally bound to the solar system, and it allows one to calculate the extent of the comet's original orbit. If the original orbit's $1/a$ value were definitely negative, it would indicate a comet from interstellar space. When the future orbit has a negative $1/a$ value, then the comet leaves the solar system forever on a hyperbolic orbit.

Since Paper I appeared, some 28 accurate osculating orbits have become available, including three which are improved orbits of comets already included in Paper I. Most of these 28 orbits are in the latest edition of the *Catalogue of Cometary Orbits* (Marsden 1982a). Two exceptions are a recent orbit for Comet Bus 1981d by Marsden (1982b), and one of Comet Seargent 1978 XV by Nakano (1979).

The calculation places the comet in its osculating orbit at the standard 40-day epoch closest to perihelion and numerically integrates backwards in time to find the original orbit, and then forward to find the future orbit. Besides the comet's orbit, those of all nine planets are integrated, taking into account the mutual perturbations of all bodies. The integrator is a 15th-order implicit Runge-Kutta method (Everhart 1974a,b). This automatically adjusted the step size when the comet approaches a planet.

The results are given in Table I. The perihelion distance is included to help correlate with the compilation in Paper I, which was sorted by perihelion distance. The quantity u_b is the adjustment in $1/a$ before epoch, and u_a is that after epoch, both in units of 10^{-6} AU $^{-1}$. Most often u_b is negative and u_a is positive, though exceptions are common. The next column gives $(1/a)_{\text{osc}}$ at epoch and its mean error in the same units. The original and

future orbits follow. Here

$$(1/a)_{\text{orig}} = (1/a)_{\text{osc}} - u_b$$

and

$$(1/a)_{\text{fut}} = (1/a)_{\text{osc}} + u_a.$$

(1)

The column labeled "Class" gives the quality class of the orbit, as explained in Paper I. Here 1A is best, 1B next, then 2A, then 2B. This notation is a change from Paper I, which used Ia, Ib, IIa, and IIb for these classes. The errors in the calculation of u_b and u_a are of the order of 0.1 units. The results are rounded to the nearest unit because the errors in $(1/a)_{\text{osc}}$ are so much larger, as seen in Table I.

When $(1/a)_{\text{orig}}$ is positive and less than 100 units, which is far less than typical planetary perturbation values, it is quite probable that a comet is making its first appearance, as one coming from Oort's cloud. Paper I discusses this at length. Here from the original orbit and its mean error (which is ordinarily the same as the error in the value at epoch), it appears that 1973 IX, 1975 II, 1975 VIII, 1976 IX, 1977 IX, 1978 XIII, 1978 XXI, 1979 VI, 1979 VII, and 1980b are comets from Oort's cloud; and that 1931 IV, 1976 XII, and possibly 1981c might be such. The only apparently hyperbolic original orbit is that of 1942 VIII, but its negative excess is not large. Whether this is due to errors in its energy at epoch in excess of its formal mean error, or whether it is a real hyperbolic orbit, we cannot say. It should be noted that neglecting the effect of nongravitational forces tends to make an orbit appear more hyperbolic than it really is. However, this comet's large perihelion distance would tend to minimize this nongravitational effect.

Two of the comets suffered extremely large perturbations, in both cases before perihelion. Thus Comet Ryves 1931 IV passed only 0.167 AU in front of Jupiter and gained 8698 $1/a$ units in that close encounter, and Comet Bowell 1980b passed just 2.697 AU behind Saturn, and then 0.228 AU behind Jupiter, losing 17066 $1/a$ units in this extraordinary double encounter. Comet Bowell's present orbit is the most hyperbolic on record,

TABLE I. Original and future orbits for 28 comets. After the names of the comets and their perihelion values q (in AU) are listed u_b , the adjustments in $1/a$ before epoch, and u_a , the adjustments after epoch. The next column gives the osculating values of $1/a$ at epoch. This is followed by two columns giving the original and future values of $1/a$, all these values being in units of 10^{-6} AU^{-1} . The last column is the quality class of the orbit. The three entries preceded by asterisks give improved results for comets which have already appeared in Paper I. The mean error for 1931 IV is our estimate.

Comet		q	u_b	u_a	$(1/a)_{\text{osc}}$	$(1/a)_{\text{orig}}$	$(1/a)_{\text{fut}}$	Class
1931 IV	Ryves	0.075	+ 8 698	- 192	+ 8 998 $\pm$ (200)	+ 300	+ 8 806	2A
1939 IX	Friend	0.945	- 356	+ 605	+ 2 971 $\pm$ 334	+ 3 327	+ 3 576	2B
1942 VIII	Oterma	4.113	- 740	+ 491	- 774 $\pm$ 13	- 34	- 282	1A
1972 III	Bradfield	0.927	- 275	+ 230	+ 2 022 $\pm$ 130	+ 2 297	+ 2 252	2A
1973 IX	Gibson	3.842	- 238	+ 59	- 167 $\pm$ 14	+ 71	- 109	1B
*1973 X	Sandage	4.812	- 543	+ 520	- 12 $\pm$ 18	+ 531	+ 508	1A
*1975 II	Schuster	6.881	- 364	+ 361	- 313 $\pm$ 9	+ 51	+ 48	1A
*1975 VIII	Lovas	3.011	+ 96	+ 385	+ 132 $\pm$ 2	+ 36	+ 517	1A
1976 IV	Bradfield	0.848	- 2 736	- 57	+ 7 301 $\pm$ 300	+ 10 036	+ 7 243	2A
1976 IX	Lovas	5.857	- 708	+ 860	- 671 $\pm$ 24	+ 37	+ 189	1A
1976 XII	Lovas	5.715	- 756	+ 710	- 613 $\pm$ 41	+ 142	+ 97	1B
1977 IX	West	5.606	- 562	+ 428	- 529 $\pm$ 10	+ 33	- 102	1A
1977 X	Tsuchinshan	3.603	- 153	+ 388	+ 161 $\pm$ 41	+ 314	+ 549	1B
1977 XIV	Kohler	0.991	+ 225	+ 855	+ 459 $\pm$ 10	+ 234	+ 1 314	1B
1978 XIII	Machholz	1.772	- 250	+ 467	- 235 $\pm$ 52	+ 15	+ 232	1B
1978 XV	Seargent	0.370	- 868	- 67	+ 4 377 $\pm$ 306	+ 5 245	+ 4 309	2B
1978 XXI	Meier	1.137	- 772	- 281	- 743 $\pm$ 4	+ 29	- 1 023	1A
1979 VI	Torres	4.687	- 268	+ 81	- 226 $\pm$ 14	+ 42	- 145	2A
1979 VII	Bradfield	0.413	- 174	+ 268	- 142 $\pm$ 23	+ 33	+ 126	2A
1979 IX	Meier	1.432	+ 136	+ 571	+ 18 716 $\pm$ 64	+ 18 580	+ 19 287	2A
1979 X	Bradfield	0.545	- 522	- 1	+ 22 661 $\pm$ 296	+ 23 184	+ 22 660	2B
1980 XII	Meier	1.520	- 456	+ 531	+ 3 516 $\pm$ 23	+ 3 973	+ 4 047	1B
1980 XV	Bradfield	0.260	+ 95	+ 815	+ 1 058 $\pm$ 20	+ 964	+ 1 873	1B
1980u	Panther	1.657	+ 38	+ 426	+ 619 $\pm$ 9	+ 581	+ 1 045	1A
1981g	González	2.334	- 641	+ 161	+ 259 $\pm$ 140	+ 900	+ 420	2A
1981d	Bus	2.458	- 304	+ 300	+ 398 $\pm$ 65	+ 703	+ 699	1B
1981c	Elias	4.742	- 281	+ 128	- 126 $\pm$ 26	+ 155	+ 2	1B
1980b	Bowell	3.364	- 17 066	+ 1023	- 17 003 $\pm$ 12	+ 63	- 15 980	1A

but Table I shows an original elliptical orbit, possibly from Oort's cloud. This does not agree with an original orbit for this comet by Hasegawa, Nakano, and Yabushita (1981), who find a hyperbola. Possibly the explanation lies in that their osculating orbit was obtained with

positional data of a short arc through March 1981 when the comet was inbound and far from the Sun. The present orbit uses data through April 1982 and thus includes that of perihelion passage and a long arc. The result for Comet Bowell is quite sensitive to the details of the oscu-

TABLE II. Changes in $1/a$ for 16 comets which do not yet have a definitive osculating orbit. After the perihelion distance a (in AU) are listed two sets of values for u_b and u_a , the first set for values before and after perihelion, the second for values before and after the standard 40-day epoch nearest perihelion. Asterisks preceding the first three entries indicate that these are recalculated because of errors in the elements used by Everhart and Raghavan (1970) in their similar table for 392 comets.

Comet		q	u_b	(peri.)	u_a	u_b	(epoch)	u_a
*1854 I	van Arsdale	2.045	- 700		+ 269	- 699		+ 268
*1854 III	Klinkerfues	0.648	- 327		+ 225	- 327		+ 225
*1871 II	Tempel	1.083	- 189		+ 284	- 178		+ 273
1970 I	Daido-Fujikawa	0.066	- 400		+ 445	- 400		+ 445
1970 VI	White-Ortiz-Bolelli	0.009	- 748		+ 114	- 748		+ 114
1970 X	Suzuki-Sato-Seki	0.405	- 820		+ 234	- 816		+ 230
1973 III	Huchra	0.973	+ 410		+ 420	+ 413		+ 418
1974 VIII	Cesco	1.373	- 236		+ 255	- 223		+ 242
1974 XV	Bennett	0.865	- 845		+ 181	- 850		+ 185
1976 V	Bradfield	0.678	- 757		+ 4316	- 757		+ 4316
1977 VIII	Helin	1.118	- 132		+ 191	- 133		+ 193
1978 VII	Bradfield	0.437	- 233		+ 171	- 228		+ 166
1978 XVIII	Bradfield	0.432	- 260		+ 117	- 257		+ 114
1980 II	Torres	2.584	- 818		+ 31	- 820		+ 34
1980 IV	Cernis-Petrauskas	0.523	- 170		+ 776	- 168		+ 774
1980/	Russell	2.111	- 791		+ 441	- 789		+ 439

lating orbit because of the very close encounter with Jupiter.

For long-period comets the changes in $1/a$, namely u_b and u_a , are not particularly sensitive to the value of $1/a$ at epoch. In the absence of an osculating orbit these changes can be calculated quite well by setting $(1/a)_{\text{osc}} = 0$, that is by starting with the parabolic elements at epoch. Then the orbit is integrated to find the changes in $1/a$, original and future. Such precalculated values of u_b and u_a are given in Table II for 16 comets. Of course $(1/a)_{\text{osc}}$ is not really zero, and from these values alone one can conclude nothing about the origins of these comets. However, when a definitive osculating orbit becomes available for one of these comets, then the original and future orbits can be found immediately with Eqs. (1). We compared the early list of u_b and u_a values found by Everhart and Raghavan (1970) with the exact solutions calculated in Paper I from the correct osculat-

ing orbits. For 20 randomly selected comets common to both lists, the mean difference in u_b and u_a was 0.8 units (of 10^{-6} AU^{-1}). For the 20 comets the values of $(1/a)_{\text{osc}}$ ranged from + 1236 to - 845 in the same units. The three 19th-century comets, marked by asterisks in Table II, are recalculated because the elements used for them by Everhart and Raghavan were grossly in error. Table II is complete. It includes every long-period comet observed since 1970 for which a definitive osculating orbit is not yet available, except for 1979 XI, which apparently hit the Sun (Sekanina 1982).

At the University of Denver the National Science Foundation supported the early part of this work. The computer time made available by the National Center for Atmospheric Research, also sponsored by the National Science Foundation, is sincerely appreciated.

REFERENCES

- Everhart, E. (1974a). *Celest. Mech.* **10**, 35.
 Everhart, E. (1974b). Denver Res. Inst. Tech. Report, 1 July.
 Everhart, E., and Raghavan, N. (1970). *Astron. J.* **75**, 258.
 Hasegawea, I., Nakano, S., and Yabushita, S. (1981). *Mon. Not. R. Astron. Soc.* **196**, 45P.
 Marsden, B. G. (1982a). *Catalogue of Cometary Orbits*, 4th edition, (Smithsonian Astrophysical Observatory, Cambridge, Massachusetts).
- setts).
 Marsden, B. G. (1982b). *Minor Planet Circ.* No. 6945.
 Marsden, B. G., Sekanina, Z., and Everhart, E. (1978). *Astron. J.* **83**, 64 (Paper I).
 Nakano, S. (1979). Nakano Note NK359 (distributed privately from Sumoto, Japan).
 Sekanina, Z. (1982). *Astron. J.* **87**, 1059.