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by Fred L. Whipple

SUMMARY

This paper follows the broadly accepted theory that Oort-Cloud Comets originated in the Solar Nebula in the general region where the major planets, Jupiter and Saturn, were formed while the Kuiper-Belt Comets originated farther out where the temperatures were lower.

The Oort-loud Comets are identified orbitally by long periods and random inclinations and, including the Halley-type comets, comets with a Tisserand Criterion less than 2.0. Kuiper-Belt comets are identified by short periods, usually much less than 200 years, and small inclinations to the ecliptic.

Here two criteria for comet activity are found to separate the two classes of comets. These quantities NG1 and NG2, were intended to measure theoretical nongravitaional effects on comet orbits. They are only mildly successful in correlations with observed cases of measured non-gravitational forces. But, in fact, their variations with perihelion distance separate the two classes of comets.

The results are consistent with the theory that the activity or intrinsic brightness of Oort-Cloud Comets fall off faster with increasing perihelion distance that does the intrinsic brightness of short-period Kuiper-Belt Comets. This suggests that the Oort-Cloud comets

were formed at higher temperatures than the Kuiper-Belt Comets and contain fewer of the more volatile ices such as CO or Ne. In addition, the oldest short-period comets act like Oort-Cloud Comets, presumably because they are the remaining central cores of very much larger comets that were warmed by radioactivity near their centers and lost the ices more volatile than water ice.

Introduction

It is now commonly held that the long-period comets ($P > 200$ yr), having a wide distribution of orbital inclinations to the ecliptic (i), originated largely in the regions of the major planets, particularly in the Jupiter-Saturn-Uranus region of the early solar nebular disk. These comets were thrown into large high inclination orbits by perturbations of the major planets and are known as Oort-Cloud Comets. As Oort (1950) postulated, many of them have been thrown back to orbits with perihelions within the inner solar system by perturbations of passing stars and, more recently, by galactic tides (see Matese and Whitmire 1996).

On the other hand, Kuiper (1950) showed that many comets must have been formed in more remote regions of the solar system near the plane near Neptune and beyond, the so-called Kuiper-Belt (Edgeworth 1949, Kuiper 1951). Duncan, Quinn and Tremaine (1988, see also Hollman and Wisdom 1993) have shown how the Short-Period (SP) comets can come largely from this region of space.

In this paper the Oort-cloud comets will include those with periods exceeding 200 years and also the so called Halley-type comets with somewhat shorter periods, a wide distribution of inclinations and a Tisserand Criterion (C) less than 2.0, where

$$C = 1/a^1 + 2\sqrt{a^1(1-e^2)}cosi, \quad (1)$$

a^1 being the semi-major axis in units of Jupiter's semi-major axis (5.203 AU), e, the usual eccentricity and, i, the inclination essentially to the ecliptic plane.

The goal of this paper is to find criteria based on the orbits and brightness variations of comets that differ between the Oort-cloud and the SP-comets. An attempt was made to simulate the non-gravitational forces acting physically on the comets and find how these quantities depend upon perihelion distances and also upon the "AGES" of the SP comets. These "AGES" were derived by the author from calculations of past orbits of the SP comets in a catalogue kindly made available by Harold F. Levison and Martin J. Duncan (1995). The "AGES" were condensed into 10 categories (1 to 10), the newest being of "AGE" 1 and the oldest of "AGE" 10. The former (1) had probably made no more than three small-perihelion passages, the latter (10) probably more than a 1000, including Comet Encke, well known for being old.

The Basic Observational Data

Besides the orbital quantities perihelion distance, q (in AU) and inclination, i, two different magnitudes are used, h_N, the absolute nuclear magnitude observed at extreme solar distances when the comet is inactive and the usual absolute magnitude, H_{10}, observed when the comet is active, nearer perihelion.

If m_n is an observed nuclear magnitude when the comet is inactive, h_{N} is then defined as

$$h_{\mathrm{N}} = m_n - 5log(r\Delta), \tag{2}$$

where r is the solar distance and Δ is the geocentric distance, both measured in AU.

When the comet is active with an observed magnitude of m, H_{10} is defined as

$$\mathrm{H}_{10} = m - 5log\ r^2\Delta. \tag{3}$$

In an attempt to simulate non-gravitational forces in comet motions the quantities NG1 were postulated from three parts. The first part is the ratio of the comet's area (R^2) to volume (or mass) the nucleus being assumed to be spherical (highly idealized!) of radius R. This led to quantity $0.5h_{\mathrm{N}}$ because

$$log\ R = constant - 0.2h_{\mathrm{N}}. \tag{4}$$

The third part is a term -0.625 $log\ r$ representing the velocity of gas sublimated from the comet varying as r^{-4}. The surface temperature (T) heated by sunlight should vary as r^{-2} and the velocity of gas, therefore as $T^{1/2}$ or r^{-4}.

Thus the quantity NG1 is defined as

$$\mathrm{NG1} = 0.5h_{\mathrm{N}} - H_{10} - 10.625\ log\ q, \tag{5}$$

there being left over a constant term that cannot be evaluated, and NG1 being measured in the magnitude system (sign reversed), and H_{10} reduced to its perihelion value at q.

A second idealized non-gravitational term is NG1 divided by the solar gravitational attraction to the comet, being the relative non-gravitational acceleration, NG2, defined as

$$\mathrm{NG2} = \mathrm{NG1} + 5\ log\ q. \qquad 6$$

Table 1 lists the data for 85 short-period comets assumed to have mostly originated in the Kuiper Belt. Their names are abbreviated to 9 spaces and they are, also identified by the P(=Periodic) numbers from the 1996 (11th Ed) of the Catalogue of Cometary Orbits, by Brian G. Marsden and Gareth V. Williams. From this catalogue a measure of non-gravitational motion is indicated by an * in the columns A_1 or A_2. The AGE's in column 7 were described in the introduction and h_N by Eq.(2), H_{10} by Eq.(3), NG1 by Eq.(5) and NG2 by Eq.(6).

The values of H_{10} in Table 1 were taken from the tables published by L. Kresák and M. Kresáková (1987) while the values of h_N were derived from the tables and graphs published by Lars Kamél (1991) and various sources.

In column (10) are values of the Dust/Gas ratio, D/G (log_{10} scale, deviations from the mean of all), as listed by A'Hearn *et al.* (1995).

Table IIA lists the data for the Halley-type comets defined above as periodic comets in the range 20 to 200 years having a Tisserand Criterion, Eq.(1), less than 2.0. The quantities in Table IIA are the same as in Table I and derived in the same fashion.

Table IIB is similar to Tables I and IIA except the values of $1/a$ original (1/AU) is included in column 5 and values of H_{10} are those derived by the author from the observations made by Von M. Beyer and published in 42 papers in the Astromomishe Nachrichten by Beyer (1969). The values of h_o were derived by the author from several sources and the observers are listed (Whipple 1991).

Table IIC differs from Table IIB only that values of H_{10} are those compiled by David W. Hughes (1987) and that the values of h_N were obtained from a number of sources but observed mostly by E. Romer (80%).

Analysis

The correlations of NG1 and NG2 with the perihelion distances of the comets were made by least-square solutions of the following equation

$$\mathrm{NG1 \text{ or } NG2} = \mathrm{A} + \mathrm{QF}\ log\ q\ (\mathrm{AU}), \qquad 7$$

for the q-factor, QF, for each comet of all classes. These results are listed in Table III for the short period comets and in Table IV for the Oort-Cloud comets.

In Table III the AGE classes are listed in Col. 1, the number of comets in Col. 2, the QF values following for both NG1 and NG2. Each QF value is followed by the standard deviation, σ, of the solution and in ( ) the standard deviation of a single comet measure of NG1 or NG2.

As will be seen in Figure 1 of NG1 for the middle 58 short-period comet group, the data apply mostly to comets with q near to or greater than 1 AU, while the major comets of the Oort-Cloud comets to follow in Table IV (see Figures 2 and 3) have their values of QF determined heavily by comets with $q < 1$ AU. For this reason Table IV is divided into two sections, the first including solutions for all the comets and the second those for comets with $q \gtrsim 0.8$ AU.

Table IV is similar in form to Table III except the solutions are identified with the number of comets from each of the Tables IIA, IIB, and IIC, all Oort-Cloud Comets.

Conclusions

The correlation of NG1 and NG2 with measured non-gravitational forces turned out to be rather disappointing. For those comets having measured non-gravitational forces, the residuals of the solutions for QF were averaged and compared to the average residual for QF for the remaining comets.

For NG1 for the average is only $+0.35 \pm 0.12$ whereas the typical σ of one observation is the order of 1.0.

For NG2 the average residual is equal to its standard deviation $+0.15 \pm 12$. Perhaps no positive correlation should have been expected.

On the other hand, the differences between the perihelion factors, QF, for the Oort-Cloud comets are in all cases smaller than for the short-period comets. The NG1 and NG2 quantities are rough measures of the relative increase of the comets activity from quiescence at great solar distances, to its maximum near perihelion. That these measures, particularly NG1, are so conspicuously greater for the short-period comets is strong evidence that the short-period comets (if of Kuiper-Belt origin) were formed at lower temperatures than the Oort-Cloud comets. That is, they should contain a much greater proportion of ices such as CO and Ne that freeze at lower temperature than water ice. The Oort-Cloud comets appear to be activated primarily by water ice and thus brighten much less conspicuously with perihelion distance.

Further support for these ideas arises from the fact that oldest short-period comets brighten as measured by the q-factor less at increasing perihelion distances than the younger ones, but almost identically as the Oort-Cloud comets. The oldest comets are the core regions of very large original comets. In such comets radioactivity heats the cores and forces the more volatile ices as freezing vapor to the outer regions (see e.g. Whipple and Stefanik 1966) and leaves the core regions primarily with water ice and non-volatile solids, probably in rather large grains.

Alternatively, very large comets may have started their accumulation earlier than the smaller comets at a time when the temperature was higher in the solar nebular disk.

The ratio of dust to gas correlates somewhat with the age of SP comets. Sixteen SP comets of AGES 1 to 6 average a D/G ratio of $+0.29 \pm 0.06$ while the eleven older average -0.10 ± 0.05. The very old comet Encke has D/G=-0.70 on this scale of A'Hearn et al.

Halley-type comets (7) average D/G= -0.06 ± 0.15, like the older SP comets but both are old so this does not distinguish SP comets from Oort-Cloud comets.

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TABLE I. SHORT-PERIOD COMETS

Comet	No.	Log q	i	A_1	A_2	Age	h_H	H_{10}	NG1	NG2	D/G
Arend	50	+0.267	19.9	*	*	2	16.3	8.1	−2.8	−1.5	—
Aren Riga	49	+0.160	17.8	–	–	3	16.4	9.3	−2.8	−2.0	+0.51
Ashb Jack	47	+0.363	12.5	*	*	2	15.3	5.1	−1.3	+0.5	—
Boethin	85	+0.047	5.8	–	–	4	15.0	7.8	−0.8	−0.6	−0.37
Borrelly	19	+0.120	30.2	*	*	3	15.8	7.6	−1.0	−0.4	+0.21
Bowl. Skif.		+0.287	3.8	–	–	2	16.1	9.2	−4.2	−2.8	—
Brooks 2	16	+0.267	5.6	*	*	6	16.6	7.3	−1.8	0.5	+0.70
Bus	87	+0.341	2.6	–	–	7	16.1	8.0	−3.6	−1.9	−0.17
Chur.Gera	67	+0.116	7.1	*	*	3	16.4	8.3	−1.3	−0.8	+0.44
Ciffreo	108	+0.231	13.1	–	–	8	16.9	7.8	−1.8	−0.6	+0.77
Clark	71	+0.191	9.5	–	*	6	17.7	8.9	−2.6	−1.6	—
Comas Sola	72	+0.272	13.0	*	*	5	15.6	6.6	−1.7	−0.3	—
Daniel	33	+0.218	20.1	*	*	3	17.5	9.2	−2.8	−1.7	—
D'Arrest	6	+0.111	19.4	*	*	9	17.4	9.5	−2.0	−1.4	−0.47
Denn.Fuji.	72	−0.108	8.6	–	*	10	19.1	13.1	−2.4	−2.9	—
deVic.Swi.	54	+0.211	3.6	–	*	4	17.6	8.7	−2.1	+1.0	—
duTo.Hart.	79	+0.079	2.9	*	*	5	19.1	11.4	−2.7	−2.3	—
Enke	2	−0.470	11.9	*	*	10	17.9	9.2	+4.7	+2.4	−0.70
Faye	4	+0.202	9.1	*	*	5	15.6	6.5	−0.8	+0.2	+0.99
Finlay	15	+0.021	3.4	*	*	5	18.1	9.5	−0.7	−0.6	—
Forbes	37	+0.170	6	*	*	2	16.9	8.8	−2.2	−1.3	—
Gale	34	+0.073	11.7	–	–	10	13.6	9.5	−3.4	−1.5	—
Gehrels 2	78	+0.373	6.7	–	–	2	16.2	7.1	−3.0	−1.1	+1.08
Gehrels 3	82	+0.535	1.1	–	–	5	16.0	4.4	−2.1	+0.6	—
Giac.Zinn.	21	+0.012	31.9	*	*	7	18.1	9.2	−0.3	−0.2	−0.27
Grig.Skje	26	−0.005	21.1	*	*	7	18.7	11.4	−2.0	−2.0	0.28
Gunn	65	+0.391	10.4	*	*	3	14.3	5.4	+2.4	−0.4	−0.28
Hane Camp	78	+0.042	6.0	–	–	3	19.4	11.4	−2.1	−1.9	—
Harrington	51	+0.203	8.7	–	*	4	17.2	9.3	−2.9	−1.8	—
Harr.Abel.	52	+0.252	16.8	–	*	8	17.1	9.6	−3.7	−2.5	—
Harr.Wils.		+0.221	16.3	–	–	2	17.1	8.7	−2.5	−1.4	—
Harring.3	110	+0.390	11.7	–	–	4	15.7	6.0	−2.3	−0.4	—
He.Ro.Cr.	111	+0.540	4.2	–	–	1	15.7	4.0	−1.9	+0.8	—
Holmes	17	+0.334	19.2	*	*	3	16.5	6.0	−1.3	+0.4	—
Ho.Mr.Pa.	45	−0.260	13.2	*	*	8	17.9	10.8	+0.9	−0.4	−0.62
Howel	88	+0.208	5.6	–	–	2	16.2	8.2	−2.3	−1.3	+0.47
Jack.Neuj.	58	+0.155	14.1	*	*	10	17.4	9.4	−2.3	−1.6	—
Johnson	48	+0.362	13.7	*	*	9	16.2	7.2	−2.9	−1.1	—
Kear.Kwee	59	+0.347	9.0	–	*	5	16.1	6.7	−2.3	−0.6	+0.31
Klemola	68	+-.247	10.6	–	*	5	16.0	8.5	−3.1	−1.9	+0.82

Comet	No.	Log q	i	A_1	A_2	Age	h_H	H_{10}	NG1	NG2	D/G
Kohoutek	75	+0.250	5.9	*	*	6	17.0	9.1	−3.3	−2.0	—
Kojima	70	+0.383	0.9	–	–	5	17.0	7.2	−2.7	−0.9	—
Kopff	22	+0.198	4.7	*	*	9	16.6	8.5	−2.3	−1.3	0.00
Kowal 1	99	+0.670	4.4	–	–	1	14.4	2.7	−2.6	+0.7	—
Kowa.Vave		+0.416	4.3	–	–	3	12.7	6.9	−5.0	−2.9	—
Longmore	77	+0.380	24.4	–	*	3	15.6	5.9	−2.1	−0.2	—
Lovas 1	93	+0.225	8.7	–	–	6	15.2	8.1	−2.9	−1.8	—
Maury	115	+0.303	9.4	–	–	6	16.8	8.3	−3.1	1.6	—
McNau.Hu		+0.327	7.3	–	–	3	16.3	8.0	−3.3	−1.7	—
Neujmin 1	28	+0.191	14.2	–	–	5	13.4	8.0	−3.3	−2.3	+0.58
Neujmin 2		+0.126	10.6	–	–	10	14.7	9.5	−3.5	−2.0	—
Neujmin 3	42	+0.296	3.9	*	*	7	16.7	8.1	−2.8	−1.3	—
Oterma	39	+0.530	4.0	–	–	4	13.4	4.1	−3.0	−0.4	—
Park. Hart.	119	+0.481	5.2	–	–	6	11.9	3.1	−2.3	+0.1	—
Perr. Mrke.	18	+0.062	15.9	*	*	8	20.2	10.6	−1.2	−0.8	—
Pete. Hart.	80	+0.211	29.8	–	–	9	15.9	8.2	−2.5	−1.4	—
Pons Winn.	7	+0.050	22.3	*	*	5	17.3	9.0	−1.3	−0.9	—
Reinmuth 1	30	+0.180	9.1	*	*	7	16.6	7.8	−2.3	−1.0	—
Reinmuth 2	44	+0.277	7.0	*	*	8	16.3	7.8	−2.6	−1.2	—
Russell 1	83	+0.207	22.7	–	–	7	18.3	10.5	−3.5	−2.5	—
Russell 2	89	+0.334	12.5	–	–	5	17.3	7.8	−2.7	−1.0	—
Russell 3	91	+0.400	14.2	–	–	2	14.8	5.9	−2.8	−0.8	—
Sanguin	92	+0.259	18.7	–	–	10	15.7	8.5	−3.5	−2.2	—
Shaumass	24	+0.078	12.0	*	*	9	16.3	7.8	-0.5	−0.1	—
Schuster	106	+0.212	20.5	–	–	7	18.6	9.2	−2.2	−2.2	—
Schw. Wach. 2	31	+0.329	3.7	*	*	1	15.5	6.4	−2.1	−0.5	+0.39
Schw. Wach. 3		−0.026	11.4	*	*	10	17.5	10.6	−1.6	−1.7	—
Shaj. Scha.	61	+0.349	6.2	–	*	1	17.5	6.8	−1.8	0.0	—
Shoemaker 1	102	+0.298	26.2	–	–	3	16.9	5.7	−1.4	+0.1	+0.31
Shoemaker 2		+0.121	21.6	–	–	9	17.8	11.5	−3.9	−3.3	—
Shoe.Holt		+0.485	4.4	–	–	1	14.3	4.1	−2.1	−0.3	—
Sing. Brew.	105	+0.307	9.2	–	–	7	16.7	8.9	−3.8	−2.3	—
Slau.Burh.	56	+0.406	8.2	–	–	7	16.7	6.7	−2.7	−0.6	—
Smur.Cher.	74	+0.551	6.6	–	–	1	14.4	4.0	−2.7	+0.1	+0.65
Spacewat.		+0.188	10.0	–	–	8	17.7	7.8	−0.9	0.0	—
Spitaler	113	+0.259	12.9	–	–	2	17.5	7.8	−1.8	−0.5	—
Swif.Gehr.		+0.134	9.2	*	*	9	16.5	7.7	−0.9	−0.2	—
Takamizaw 1	98	+0.203	9.5	–	–	4	16.2	7.8	−1.8	−0.8	+0.46
Taylor	69	+0.292	20.5	–	–	2	16.5	8.3	−3.1	−1.7	—
Temple 1	9	+0.173	19.6	–	–	8	16.6	7.5	−1.0	−0.2	+0.04
Temple 2	10	+0.140	12.4	*	*	8	16.8	7.6	−0.7	0.0	−0.10
Tscuhins 1	60	+0.249	6.7	–	–	7	18.5	8.8	−2.2	−1.0	—

Comet	No.	Log q	i	A_1	A_2	Age	h_H	H_{10}	NG1	NG2	D/G
Tu.Gi.Kr.	41	+0.061	9.2	*	*	9	19.1	10.5	−1.6	−1.3	—
Urat.Niij.	112	+0.161	24.3	–	–	6	24.3	11.9	−4.7	−3.9	—
VanBiesb.	68	+0.379	6.8	–	–	4	14.7	5.9	−2.6	−0.7	—
We.Ko.Ik.	76	+0.196	30.6	*	*	1	18.3	7.8	−0.7	+0.2	—
Whipple	36	+0.488	99	*	*	6	16.0	6.2	−3.4	−0.9	—
Wild 1	64	+0.297	19.9	–	–	10	16.1	5.0	−3.7	−2.2	—
Wild 2	81	0.184	3.3	*	*	1	14.6	6.5	−1.2	−0.2	+0.45
Wild 3	86	+0.359	15.5	–	–	8	17.0	6.2	−1.5	+0.3	—
Wirtanen	46	+0.035	11.7	*	*	2	18.2	8.3	−0.1	+0.1	−0.21
Wise. Skif.	114	+0.178	18.2	–	–	6	17.8	10.4	−3.3	−2.5	—
Wolf	14	+0.399	27.3	*	*	9	17.0	6.3	−2.0	0.0	—
WolfHarr.	43	+0.208	18.4	*	*	6	15.9	7.9	−2.2	−1.1	+0.22

TABLE IIA. HALLEY-TYPE COMETS

Comet	No.	Log q	i	A_1	A_2	Age	h_H	H_{10}	NG1	NG2	D/G
Bradfield 1		+0.133	5.8	–	–	9	14.2	7.0	−1.3	−0.6	—
Bror.Mete.	23	−0.320	19.3	*	*	9	17.6	7.5	+4.7	+3.1	−0.76
Crommelin	27	−0.134	29.1	*	*	9	16.7	8.9	+0.9	+0.2	−0.14
Halley	1	−0.231	162.2	*	*	9	15.0	2.8	+7.1	+6.0	+0.36
Hart. Iras		+0.108	95.7	–	–	–	15.0	7.5	−1.1	−0.6	+0.05
Hers. Rigo.	34	−0.126	64.2	–	–	6	14.6	7.9	+0.7	+0.1	—
Levy	51	−0.008	19.2	–	–	9	14.2	6.1	+1.1	+1.1	—
Machholz	96	−0.897	60.0	–	–	10	19.5	11.2	+8.1	+3.6	—
Olbers	13	+0.071	44.6	*	*	7	15.0	3.9	+2.8	+3.2	—
Pons Brook	12	−0.112	74.9	*	*	10	11.5	4.1	+2.8	+2.3	—
Step. Oter.	38	+0.197	18.5	*	*	4	13.2	13.2	−3.5	−2.5	+0.20
Swif. Tutt.	109	−0.021	113.4	–	–	8	13.6	3.8	+3.2	+3.1	+0.33
Tuttle	8	−0.001	54.7	*	*	9	15.8	7.5	+0.4	+0.4	−0.48
Westphal		+0.098	40.9	–	–	10	15.8	5.5	+1.4	+1.8	—

TABLE IIB. LONG-PERIOD COMETS

Comet	Number	Log q	i	i/a original	h_N	H_{10}	NG1	NG2
Pelt. Whip.	C1932 P1	+0.016	7.7	−0.022945	13.7	8.8	−2.1	−2.0
Dodw. For.	C1932 Y1	+0.117	24.5	+0.024562	13.5	8.3	−2.8	−2.2
de Ko.. Para.	C1941 B2	−0.102	26.3	+0.019938	12.0	5.6	+1.5	+1.0
Whip Fedt.	C1943 X1	+0.131	19.7	+0.051559	11.6	4.5	−0.1	+0.6
Bester	C1946 U1	+0.382	108.2	−0.000013	10.9	5.0	−3.6	−1.7
Bester	C1947 S1	−0.126	140.6	+0.000024	11.2	6.0	+1.0	+0.3
Ba.Bo.Ne.	C1949 N1	+0.313	105.8	+0.000659	11.6	7.0	−4.5	−3.6
Minkowski	C1950 K1	+0.410	144.2	+0.000037	10.6	4.0	−3.0	−1.0
Peltier	C1952 M1	+0.080	45.6	+0.000141	14.4	9.3	−2.9	−2.5
Mrko Hond	C1953 G1	+0.010	93.9	+0.002983	14.6	8.0	−0.8	−0.8
Mykos	C1955 L1	−0.272	86.5	+0.020013	13.9	6.5	+3.3	+2.0
Ba.Ma.Kr..	C1955 N1	+0.154	50.0	+0.004353	13.8	7.1	−1.8	−1.1
Honda	C1955 O1	−0.053	107.5	−0.000727	12.1	7.1	−0.5	−0.7
Baade	C1954 O2	+0.588	100.4	+0.000042	10.6	3.5	+4.5	−1.5
Mrkos	C1956 E1	−0.075	147.5	Par.	16.1	10.5	−1.7	−2.0
Burnham	C1958 D1	+0.122	15.8	+0.000256	14.2	7.9	−2.1	−1.4
Burn. Slau.	C1958 R1	+0212	61.3	+0.000076	13.6	7.6	−3.0	−2.0
Burnham	C1959 Y1	−0.297	159.6	−0.000288	14.9	7.6	+3.0	+1.5
Ikeya	C1963 A1	−0.199	160.6	+0.011389	13.4	5.0	+1.5	+2.8
Ikeya Seki	C1967 Y1	+0.230	129.3	+0.000842	13.4	4.4	+2.2	+1.0
Ta.Ho.Ya.	C1968 H1	−0.167	102.2	+0.006491	16.5	10.8	−0.8	−1.6
Ball. Clay.	C1968 Q1	+0.248	93.2	Par.	13.1	7.2	−3.3	−2.0
Ta.Sa.Ko.	C1969 T1	−0.325	75.8	+0.000507	13.2	6.1	+3.9	+2.3
Abe	C1970 N1	+0.046	126.7	+0.000283	13.6	5.1	+1.2	+1.4

TABLE IIC. LONG-PERIOD COMETS

Comet	C	Number	Log q	i	i/a original	h_N	H_{10}	NG1	NG2
Whip. Para.		1940 O1	+0.034	54.7	+0.018093	12.6	10.3	−4.36	−4.19
Peltier		1952 M1	+0.080	45.6	+0.000148	14.2	9.1	−2.85	−2.45
Mrkos		1952 W1	−0.109	97.2	−0.000125	14.1	8.2	+0.01	−0.54
Vozarova		1954 O1	−0.169	116.2	+0.000049	12.7	7.0	+1.14	+0.30
Baada		1954 Y1	+0.610	79.,6	+0.000039	12.1	5.3	−5.7	−2.68
Abell		1955 G1	+0.653	123.9	+0.000082	10.5	5.1	−6.8	−3.5
Mrkos		1955 L1	−0.272	86.5	+0.020013	14.0	6.6	+3.29	+1.9
Ba.Ma.Kr.		1955 N1	+0.154	50.0	+0.004353	13.0	7.24	−2.38	−1.6
Aren.Rold.	*	1856 R1	−0.500	119.9	−0.000531	13.3	5.4	+6.6	+4.06
Wils. Hubb.		1961 O1	−1.396	24.2	+0.000782	16.7	7.52	15.7	8.7
Humason		1961 R1	+0.329	153.3	+0.004935	8.4	1.35	−0.65	+1.0
Seki		1961 T1	−0.167	199.7	+0.013565	15.6	9.3	+0.27	−0.56
Seki-Lines		1962C1	−1.503	65.0	+0.000025	16.4	6.6	+16.4	+8.8
Ikeya		1963 A1	−0.199	160.6	+0.011389	13.6	6.4	+2.51	+1.52
Pereyra		1963 R1	−2.292	144.6	+0.010697	8.4	5.6	+23.0	+11.5
To.Ge.Ho.		1964 L1	−0.301	161.8	+0.008131	14.4	8.7	+1.70	+0.19
Evehart		1964 P1	+0.100	68.0	+0.002721	14.2	7.6	−1.56	−1.06
Alcock		1965 S2	+0.112	65.0	Par.	13.9	9.1	−3.3	−2.8
Barbon		1966 P2	−0.305	28.7	+0.000643	11.5	5.52	−3.0	−1.49
Wild		1967 C1	−0.340	106.5	Par.	16.5	10.4	+1.46	−0.24
Seki		1967 C2	+0.123	99.1	Par.	12.6	10.3	−5.3	−4.69
Whit.Thom.		1968L1	+0.091	61.8	Par.	16.2	10.3	−3.2	−2.73
Ball.Clay		1968 Q1	+0.248	93.2	Par.	12.3	7.65	−4.1	−2.90
Honda		1968 Q2	+0.041	127.9	Par.	15.4	6.9	+0.36	+0.57
Wild		1968 U1	+0.417	135.2	Par.	12.5	7.5	−6.7	−3.61
Thomas		1968 Y1	+0.521	45.2	+0.001502	12.9	5.8	−4.79	−2.28
Ta.Sa.Ko.		1969 T1	−0.325	75.8	+0.000507	13.2	5.8	+4.25	+2.63
Abe		1970 N1	+0.046	126.7	+0.000283	11.5	11.0	−5.7	−5.5
Sandage		1972 L1	+0.061	78.4	+0.000069	12.7	7.5	−7.9	−4.7
Kojima		1972 U1	+0.332	141.9	+0.000320	12.5	9.5	−6.8	−5.1
Araya		1972 X1	+0.687	113.1	+0.000476	10.2	6.5	−8.7	−5.3
Heck-Sause		1973 A1	+0.400	138.6	+0.000049	11.9	7.5	−5.8	−3.8
Kohoutek		1973 E1	−0.848	14.3	+0.000020	15.0	6.0	+10.5	+6.3
Huchra		1973 H1	+0.377	48.3	+0.010888	14.5	13.0	−9.8	−7.9
Bradfield	*	1974 C1	−0.298	61.3	+0.000602	13.7	7.21	+2.8	+1.3
Lovas		1974 F1	+0.479	50.6	+0.000036	21.9	9.0	−8.1	−5.7
v.d.Berg		1974 V1	+0.780	60.9	+0.000011	10.8	6.0	−8.9	−5.0
Bradfield		1975 E1	+0.085	55.2	+0.000023	12.65	10.0	−4.6	−4.15
Mo.Sa.Fu.		1975 T1	+0.205	91.6	+0.001964	10.5	5.08	−2.0	−0.98
Su.Sa.Ko.		1975T2	−0.077	118.2	+0.017578	12.7	9.8	−2.6	−3.0

Comet	C	Number	Log q	i	i/a original	h_N	H_{10}	NG1	NG2
Schuster		1976 O2	+0.838	112.0	+0.000059	9.1	4.5	−8.9	−4.66
Kohler		1977 R1	−0.004	48.7	+0.000231	11.8	10.0	−4.1	−4.1

TABLE III. Results - SP Comets

AGES	No.	NG1 QF	NG2 QF
1	9	-2.5 ± 1.0 (0.6)	$+1.3 \pm 1.0$ (0.4)
2-7	58	-3.2 ± 0.8 (0.8)	$+1.4 \pm 1.0$ (1.0)
8	9	-5.4 ± 2.2 (1.1)	-0.5 ± 1.8 (0.9)
9	10	-3.1 ± 2.8 (1.0)	-0.1 ± 2.7 (0.9)
10	10	-9.3 ± 1.5 (1.1)	-4.9 ± 1.4 (1.0)

Table IV. Results - Oort-Cloud Comets

TABLE	No.	NG1 QF	NG2 QF
IIA	14	-9.4 ± 1.9 (1.9)	-4.4 ± 1.9 (1.9)
IIB	24	-9.4 ± 1.1 (1.3)	-4.1 ± 1.4 (1.5)
IIC	42	-11.1 ± 0.5 (1.9)	-6.0 ± 0.5 (2.0)
		Values with $q \gtrsim 0.8$ AU	
IIA	7	-20.0 ± 9.2 (1.6)	-12.5 ± 9.0 (1.6)
IIB	15	-8.3 ± 2.2 (1.3)	-1.4 ± 2.2 (1.3)
IIC	26	-7.8 ± 1.6 (1.9)	-2.1 ± 1.5 (1.9)

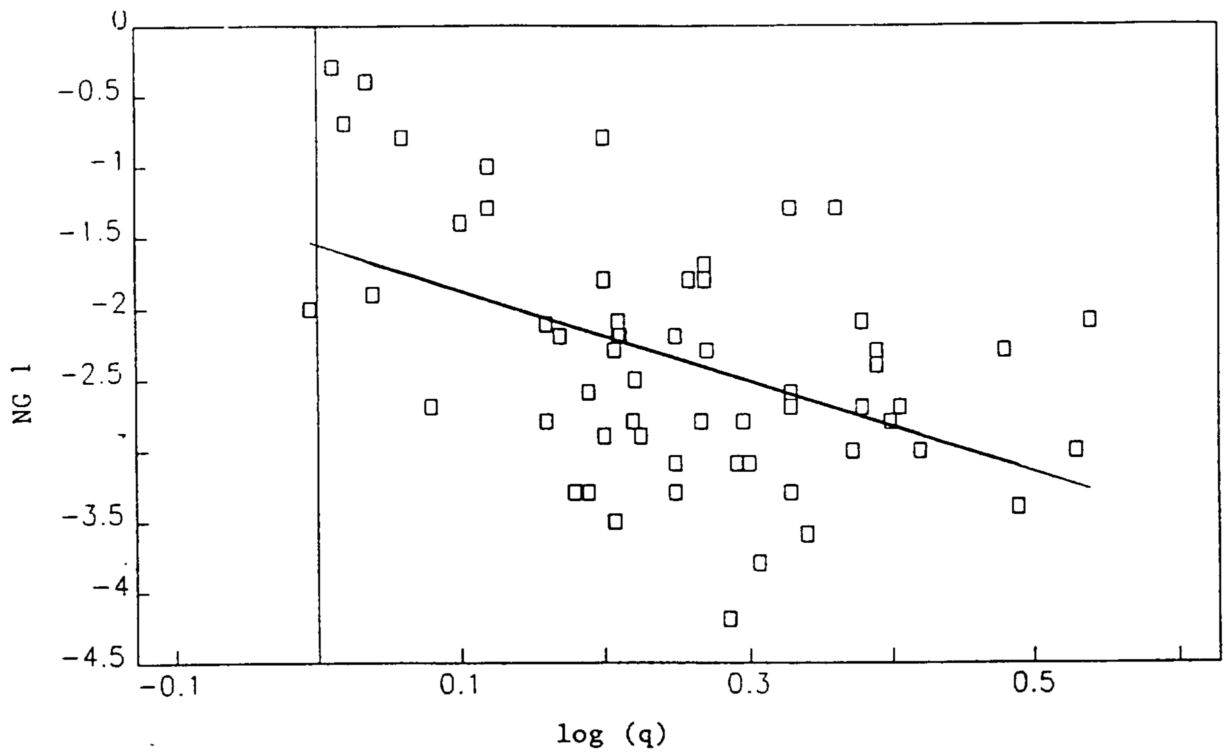

Figure 1. 58 S-P Comets.

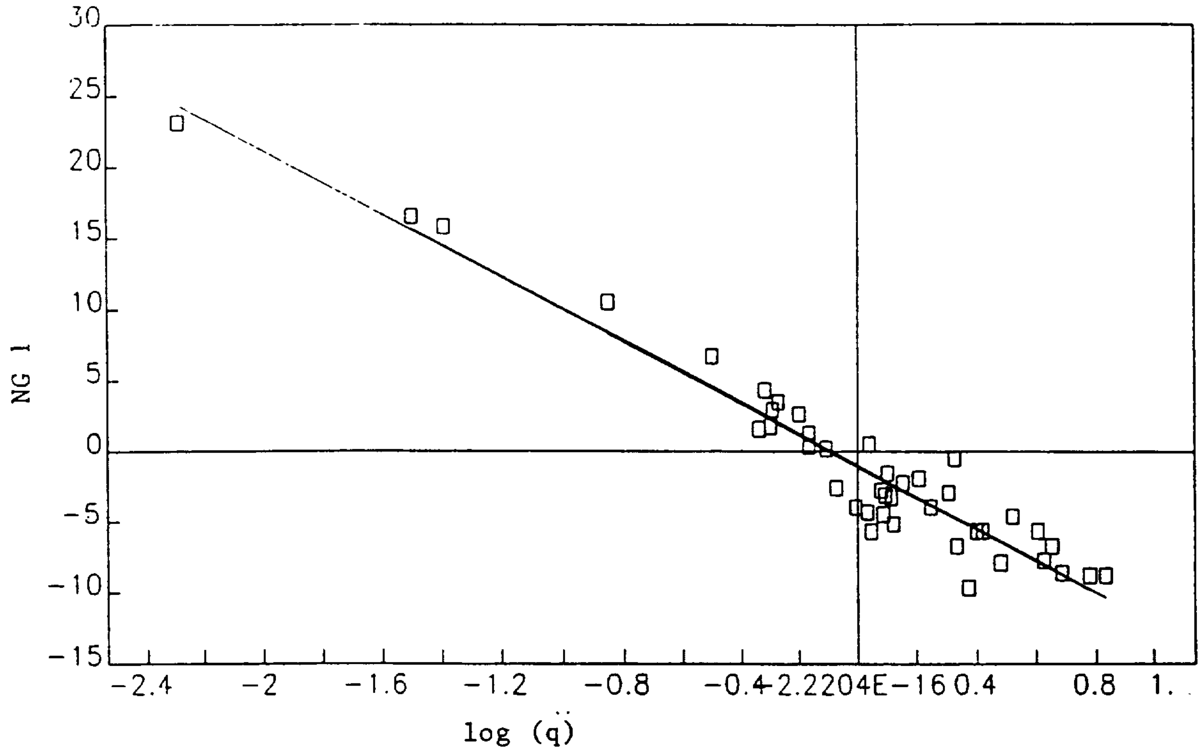

Figure 2. From Table IIC listing in Table IV.

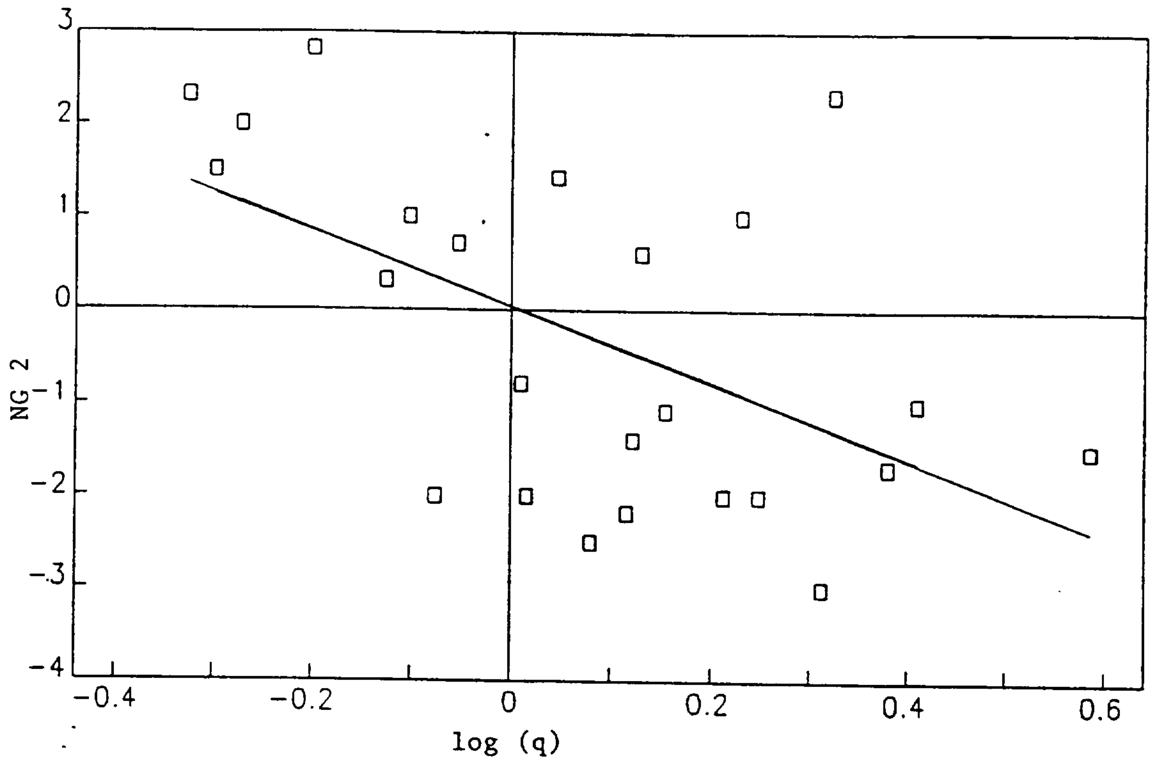

Figure 3. From Table IIB listing in Table IV.