NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-684

A Survey of Possible Missions to the Periodic Comets in the Interval 1974–2010

D. F. Bender

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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PREFACE

The work described in this report was performed by the Mission Analysis Division of the Jet Propulsion Laboratory.

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ABSTRACT

In order to survey the mission possibilities for the short period comets two catalogues are developed. In the first the physical and pertinent orbital characteristics are given for 65 short period comets. Since missions for short period comets are for the most part expected to utilize arrivals near perihelion at a time when the comet is comparatively active, the second catalogue is one containing the predicted perihelia for each of the 65 comets between 1974 and 2010. Included is enough geometry to indicate feasibility of Earth-based observation and sighting within 100 days of perihelion.

Mission selection criteria and trajectory requirements are discussed with the aim of providing the background for catagorizing the possibilities. The comets are then divided essentially on the basis of size and activity into three groups of interest from the data in the first catalogue: primary, secondary and low interest.

The perihelia are separated into two groups of interest: satisfactory and not satisfactory, essentially on the basis of Earth-comet distance.

Thus there are obtained three Tables of targets for missions to the short period comets, the first of which, for primary interest comets with satisfactory perihelia, contains 57 cases and is the main shopping list for these missions. There are 43 cases in the second table for the secondary interest comets and 42 in the third for the low interest comets. The final table presented lists chronologically the 51 perihelia for which the comet is predicted to pass within .75 AU of the Earth.

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D. F. Bender

I. Introduction

Comets display some of the most interesting and yet poorly understood processes that are taking place in the solar system. These include the normal increase in activity and total brightness as the comet approaches perihelion as well as occasional sudden changes in brightness and the production of comet tails. Periodic conferences have been held from which one can note the progress in the development of theories of comet behavior (Liege, 1966; NASA, 1971; Vsekhsvyatskii, et.al., 1972). Even so space missions in which the cometary material is actually sampled and observed at close range will be essential before further significant advances in our knowledge about these processes can be developed. An understanding of these processes is essential to the development of a theory of evolution of the solar system itself. (NASA, 1972)

In recent years many persons have contributed scientific plans and trajectory plans for comet exploration (Arrhenius, et.al, 1973 ; Roberts, 1971; NASA, 1971, 1972; Friedlander, 1971; Manning, 1970; to list only the summary papers). The great potential values to be gained from missions to comets are to discover what the nucleus is like, what the constituents really are, and how the various solar radiations produce the changes that occur. Thus more and more scientific and popular interest in a comet mission is developing.

This paper summarizes the mission possibilities for the short period comets in the next third of a century. In addition it will serve as a source of information for estimating the potentialities of missions to new short period comets as they may be discovered. Most of these comets have perihelia less than 2 AU and aphelia greater than 5 AU and are unobservable from Earth except when quite near both the Sun and Earth. Since their activity generally increases as the solar distance decrease (except that short period comets of small perihelion distance may be practically exhausted by the time they reach perihelion), missions to these comets are to be considered only for arrival near the comet perihelion and only when the comet is also relatively near the Earth. The possibility of a mission to a large new long-period comet (with a spacecraft and launch vehicle standing in readiness waiting for a satisfactory target to appear) will not be considered.

Two comet catalogues are presented. The first contains 65 short period comets listed by perihelion distance and gives some orbital data and physical characteristics, the second contains predicted perihelia from 1974 to 2010 with the comets listed alphabetically and gives some Earth - Sun - comet geometrical details for each perihelion. Next, mission selection criteria are discussed, then mission propulsion and encounter types are given so that the comets can be divided into three categories of estimated interest as targets and two categories of estimated availability as targets. Thus there is developed a set of three tables of single comet mission opportunities of primary, secondary and low importance. Some of these might be combined into multi-target missions but this possibility is not investigated here.

II Comet Catalogues

A. Comet Characteristics

Table 1 is the list of the known periodic comets which are predicted to return to perihelion in the time interval 1974 to 2010. It contains 65 comets and is taken primarily from the list of periodic comets of two or more observed appearances from the catalogue of Cometary Orbits (Marsden, 1972a). However, two comets (Brorsen and Biela) were omitted since they have not been observed for more than 100 years, and four were left out because they will not return in the desired interval. One returning comet which has been identified recently, namely Swift-Gehrels, and seven comets from those of only one appearance are added on the basis of predictions by Marsden (1972b). These are Schwassmann-Wachmann 3, Churyumov-Gerasimenko, Gunn, Klemola, Wild, DuToit 1, and Van Houten. The comets in Table 1 are arranged in order of predicted perihelion distance from the Sun, given in the first column.

The second column of the table contains an estimate of the absolute magnitude of the comet based on its observed magnitude at the last apparition. For the most part these are taken from the work of S. K. Vsekhsvyatskii and associates (1958, 1971, 1972), who generally make the assumption that the total brightness of the comet varies as the fourth power of its distance from the Sun. The dependence of total magnitude as a function of solar distance has been studied by Vsekhsvyatskii (1971) and by Beyer (1971). The results vary widely from one comet to another because comets are frequently observed over only a narrow range of solar distance and do not exhibit regularly predictable behavior. In spite of this, a set of magnitudes based on a reasonable choice for this dependence will yield values for absolute magnitude that can be compared from comet to comet to give an estimate of relative size.

The size of the coma at its maximum extent is indicated in the next column where it is given in terms of the apparent angular diameter in minutes of arc if seen at a distance of 1 AU. Again the results are taken largely from Vsekhsvyatskii (1958, 1971, 1972) and Beyer (1971). If the periphelion to which this datum refers is not the one indicated in the next column (or the one just previous) the number is given in parentheses. A double parenthesis implies very old data.

Two additional orbital elements are listed since they also have important applications for missions. The inclination is given because for rendezvous missions it is one of the important factors in determining propellant cost and for flyby it is a major factor in determining the magnitude of the encounter velocity. High inclinations are undesirable from either point of view. For example, since the inclination of 162° for Halley implies a retrograde orbit, the rendezvous mission is extremely difficult, and a flyby would occur at about 60 km/sec if a spacecraft is simply directed to intercept Halley. Even for Giacobini-Zinner with an inclination of 32° the straightforward flyby mission would pass the comet at about 30 km/sec. The orbit period is given because it measures both the interval between opportunities and the actual energy of the orbit. Again high values are undesirable for rendezvous and slow flyby missions because of the large orbital energy changes required and because of the infrequent opportunities.

The name of the comet is given next and its official designation during its most recent observed perihelion passage. This consists of the year of the perihelion passage and a Roman numeral which indicates the time sequence of the observed comet perihelion passages.

The final column of Table 1 contains comments on the characteristics of the comets as seen from the Earth. The objective is to describe briefly the structure and activity of the comet so as to indicate its relative scientific interest as a mission target. Three classes of scientific interest will be established and the comets placed in the classes on the basis of these characteristics, the absolute magnitudes (Col. 2) and the specific size (Col. 3). The sources of information regarding the appearance of individual comets are not indicated. These sources are Vsekhsvyatskii (1958, 1971), Beyer (1971), RAS (1942-72), and Roemer (1966).

Except for Halley, the periodic comets as a group are small and faint as observed from the Earth. In addition there is a kind of selection in actual size in that the known periodic comets which cannot or have not ever approached the Earth closely tend to be larger than those which have. The appearance of a comet on a photographic plate or to the eye through a telescope depends on the seeing conditions. It can appear as a hazy coma with a weak central condensation at one time and as a nearly stellar object a few days or weeks earlier or later. Also photographically, a comet image changes vastly with exposure time and with the wavelength used. In addition, the general brightness of a comet during its approach to the sun may be dependent on the solar activity at the time. Periodic comets have been observed to flare up suddenly by as much as five magnitudes (e.g. Tuttle-Giacobini-Kresak in 1973) or to fade unexpectedly. The theory that comets are continually emitting dust and/or gas from their nuclei would indicate that the periodic comets should diminish in activity over the course of several perihelia. Encke, for example (Vseksvyatskii, 1971), has decreased from an absolute magnitude of about 8 in 1800 to about 11 in 1950, and Faye has decreased from about 4 in 1850 to about 11 in 1950. Assuming a steady decrease in magnitude by 2000 A. D., Encke would have an absolute magnitude of about 12 and Faye of about 14.

In the comments on comet characteristics, the coma is described first, then the nucleus, and finally the tail. Further special comments follow. It is the coma and nucleus, i.e. the head, which is the primary characteristic that distinguishes a comet from an asteroid. In order to characterize the size of the comet for purposes of comparison the value of [illegible] of coma at 1 AU given in column 3 will be used. This is presumed to be a value estimated from either visual observations or photographic observations using standard emulsions for the visible at a time when the comet is at its greatest physical extent. The terms "very large", "large", "medium", "small", and "very small" will be applied with the following implications:

Very large, size at 1 AU greater than 3 min of arc (130000 km);

Large, size at 1 AU from 2 to 3 min of arc;

Medium, size at 1 AU from 1.2 to 2 min of arc;

Small, size at 1 AU from .3 to 1.2 min of arc;

Very small, size at 1 AU less than .3 min of arc.

Note than 1 min of arc at 1 AU corresponds to a diameter of 43,500 km. Sometimes a central condensation is very noticeable in the general brightness of the coma, even when the comet is at its brightest condition. In this case the designation "strong nucleus" will be used. The tail of a comet, if it exists, is a characteristic feature of the comet. Two major types are distinguished, namely: ion (I) or dust (II); and if the type of tail is known, it is indicated. Note that the long period comets which are naked eye objects with long tails would be classified as "large coma; weak nucleus; two very long tails (I & II). Only Halley of all the short period comets possesses these characteristics.

It will be noted that the last observation of a short period comet is not always at its latest perihelion. The failure to note the return of a periodic comet in the past could have occurred because of unfavorable geometry which caused it never to be bright enough to be detected, or because of possible breakups occurring during previous perihelion passage but not observed, or because gravitational perturbations due to a close passage to Jupiter or to Saturn had not been investigated. At present a short period comet with a recent well determined orbit is not observed only if it is too faint to be seen (magnitude greater than about 20) or has disintegrated, unless the moon interferes or there is an insufficient number of good observing nights.

B. Comet Perihelia 1974-2010.

In Table 2 there is presented a full list of the perihelia of the comets of Table 1 in the time interval from 1974 to 2010. Comets are listed alphabetically with the predicted date of perihelion in the second column. Most of the data are based on integration of the orbits of the comets in which the perturbations due to all of the planets out to Saturn have been included. The sources of information regarding the orbits of comets in future are Marsden (1973), Narin and Pierce (1964, 1965) and Yeomans). In addition B.G. Marsden provided the author a set of predicted elements for several of the less certain periodic comets (1972b). However, none of the integrated data go beyond the year 2000 and it was necessary in almost every case to propagate the trajectory using a Keplerian ellipse in order to list perihelia to 2010. The first perihelion date obtained from the previous one in this manner is indicated with an asterisk in Table 2. In order to assess the possibility of a significant gravitational perturbation, each comet orbit propagated as an ellipse was investigated for close approaches

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMETS*

(listed by perihelion distance with orbital elements for mid 1980's)

Perihelion Distance (AU)	Absolute Magnitude	Size of Coma at 1AU min	Name Recent Designation Inclination and Period	Observed Characteristics
.34	11.4	2.4	Encke 1971 II, 12°, 3.3 yr	Medium coma, fan-shaped toward sun; strong nucleus; narrow tail (I)
.48	9.6	4.8	Brorsen-Metcalf 1919 III 19°, 69.1 yr	Large coma; weak nucleus; long tail (I)
.58	11.6	1.0	Honda-Mrkos-Padjusakova 1969 V, 13°, 5.3 yr	Medium coma; weak nucleus; tail
.59	4.6	5.5	Halley 1910 II 162°, 76.0 yr	Very large coma; weak nucleus; very strong tails,
.74	10.7	1.2	Crommelin 1956 VI 29°, 27.9 yr	Medium coma; weak nucleus; no tail
.91	11.7	.61	Schwassmann-Wachmann 3 1930 VI 10°, 5.3 yr	Small coma; strong nucleus; tails (I & II) passed very close (.09 AU) to Earth before perihelion in June 1930, anomalous anti-tail
.98	13.6	((1.8))	Tempel-Tuttle 1965 IV 162°, 33.2 yr	Medium coma; strong nucleus; no tail recently
.99	14.9	(2.4)	Grigg- Skjellerup 1967 I, 1972 b 21°, 5.1 yr	Large coma; strong nucleus, no tail
1.01	10.0	2.2	Tuttle 1967 V 54°, 13.7 yr	Large coma, weak nucleus; no tail recently
1.03	11.9	2.2	Giacobini-Zinner 1966 I, 1972d 32°, 6.5 yr	Large coma; strong nucleus; long tails (I & II)

*See text for explanation of nomenclature

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMETS

Perihelion Distance	Absolute Magnitude 1 AU	Size of Coma	Name Recent Designation Inclination and Period	Observed Characteristics
1.08	14.3	.1	Wirtanen 1967 XIV 12°, 5.5 yr	Very small coma; strong nucleus; no tail recently
1.10	12.5	(1.5)	Finlay 1967 IX 4°, 7.0 yr	Medium coma; weak nucleus; no tail recently
1.12	9	10	Tuttle-Giacobini-Kresak 1962 V, 1973 b 10°, 5.6 yr	Very large coma; strong nucleus; tail brighter in 1973 than predicted
1.20	12.0	0.7	Gale 1938 I 11°, 11.1 yr	Small coma; very weak nucleus; small jet but no tail
1.21	7.8	6	Schaumusse 1960 III 12°, 8.3 yr	Very large coma; weak nucleus; long tail
1.25	13.5	(1)	Pons-Winnecke 1970 VIII 22°, 6.4 yr	Medium coma; strong nucleus; no tail recently
1.25	8.8	5.9	Westphal 1913 VI 41°, 63.0 yr	Very large coma; weak nucleus; long tail (I); faded at perihelion in 1913
1.27	10.7	1.6	Neujmin 2 1927 I 5°, 5.4 yr	Medium coma; weak nucleus; no tail
1.28	10.4	1.3	Churyumov-Gerasimenko 1969 IV 7°, 6.6 yr	Medium coma; strong nucleus; tail
1.28	11.6	.2	Du Toit 1 1944 III 19°, 14.8 yr	Very small coma; weak nucleus, no tail

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMETS

Perihelion Distance (AU)	Absolute Magnitude	Size of Coma at 1AU min	Name Recent Designation Inclination and Period	Observed Characteristics
1.29	11.5	4.1	d'Arrest 1970 VII 19°, 6.4 yr	Large fan shaped coma; weak nucleus; no tail recently
1.31	15.6	.9	Perrine-Mrkos 1968 VIII 18°, 6.8 yr	Medium coma; weak nucleus no tail (faded significantly since 1955)
1.32	12.5	(2.2)	Borrelly 1967 VIII 1973m 30°, 6.8 yr	Large oval coma; weak nucleus; no tail recently
1.36	(10.4)	((2.5))	Swift-Gehrels 1973d 9°, 9.3 yr	Large coma; weak nucleus; no tail
1.38	10.4	2	Tempel 2 1967 X, 1972 c 12°, 5.3 yr	Large fan shaped coma; weak nucleus; tail (much brighter in 1967 than predicted)
1.43	(13.3)	(.4)	Jackson-Neujmin 1970 IX 14°, 8.4 yr	Small coma; strong nucleus; short tail
1.45	12	(1.7)	Arend-Rigaux 1971 IV 18°, 6.8 yr	Weak coma, strong nucleus; no tail recently
1.48	13	(.4)	Forbes 1961 VI 5°, 6.3	Small coma; strong nucleus; no tail
1.49	14.3	.2	Tsuchinshan 1 1971 VIII 10°, 6.6	Very small coma; strong nucleus; no tail
1.50	10.4	((1.6))	Tempel 1 1966 VII, 1972 a 10°, 5.5 yr	Medium coma; weak nucleus; no tail

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMET

Perihelion Distance (AU)	Absolute Magnitude	Size of Coma at 1 AU min	Name Recent Designation Inclination and Period	Observed Characteristics
1.55	11.0	.4	Neujmin 1 1966 VI 14°, 18.2 yr	Small coma; weak nucleus; no tail
1.57	8.3	(3.5)	Kopff 1970 XI 5°, 6.4	Very large coma; strong nucleus; narrow tail
1.59	10.8	2.3	Faye 1969 VI 9°, 7.3 yr	Large coma; strong nucleus; faint diffuse tail
1.60	16.3	.2	Harrington 2 1960 VII 9°, 6.9 yr	Very small coma; weak nucleus; short faint tail
1.60	9.5	2.1	Stephan-Oterma 1942 IX 18°, 39.0 yr	Large coma; weak nucleus; tail
1.60	12.8	1.3	Tempel-Swift 1908 II 13°, 6.4 yr	Medium coma; weak nucleus; no tail
1.62	12.1	.5	Wolf-Harrington 1971 VI 18°, 6.5 yr	Small coma; strong nucleus; faint tail
1.66	16	(2.1)	Daniel 1964 II 20°, 7 1 yr	Large coma; strong nucleus; no tail recently
1.71	11.7	(.2)	Dutoit-Neujmin-DelPorte 1970 XIII 3°, 6.4 yr	Very small coma; weak nucleus; no tail recently
1.76	13.4	.2	Klemola 1965 VI 11°, 11.0 yr	Very small coma; weak nucleus; no tail

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMETS

Perihelion Distance (AU)	Absolute Magnitude	Size of Coma at 1AU min	Name Recent Designation Inclination and Period	Observed Characteristics
1.77	12.1	.3	Tsuchinshan 2 1971 X 7°, 6.8 yr	Small coma; strong nucleus; tail
1.78	14.3		Harrington-Abell 1969 III 10°, 7.6 yr	Weak coma; strong nucleus; no tail recently
1.80	13.8	(.2)	Vaisala 1 1971 VII 12°, 10.9 yr	Very small coma; strong nucleus; no tail
1.83	11.6	2.0	Comas-Sola 1969 VIII 13°, 8.8 yr	Large coma; strong nucleus fan shaped tail (I)
1.85	14.4	(1.0)	Brooks 2 1960 VI 6°, 6.9 yr	Medium coma; strong nucleus; no tail recently
1.86	13.3	(1.4)	Arend 1967 VI, 1973 j 20°, 8.0 yr	Medium coma; strong nucleus; no tail recently
1.95	11.7	.8	Reinmuth 2 1967 XI, 1973 g 7°, 6.7 yr	Small coma; strong nucleus; no tail recently
1.98	12.1	.12	Reinmuth 1 1965 V 8°, 7.6 yr	Very small coma; wide nucleus; no tail recently
1.98	12.0		Wild 1960 I 1973 c 20°, 13.3 yr	Medium coma; strong nucleus trace of narrow tail; nucleus double in 1968
2.03	13.7	.2	Neujmin 3 1951 V 4°, 10.9 yr	Very small coma; weak nucleus; no tail recently
2.14	10.1	1	Schwassmann-Wachmann 2 1968 II 1973 1 4°, 6.5 yr	Medium coma; strong nucleus; broad tail

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMETS

Perihelion Distance (AU)	Absolute Magnitude	Size of Coma at 1AU min	Name Recent Designation Inclination and Period	Observed Characteristics
2.18	14.4	.3	DeVico-Swift 1965 VII 6°, 7.4 yr	Small coma; strong nucleus; tail
2.22	8.6	3.3	Kearns-Kwee 1963 VIII, 1971 c 9°, 9.0 yr	Very large fan shaped coma; trace of tail; thick inner coma
2.23	(7.6)	(3.8)	Shajn-Schaldach 1971 IX 6°, 7.3 yr	Very large coma; weak nucleus; tail
2.31	6.7	(2.0)	Ashbrook-Jackson 1971 III 12°, 7.5 yr	Large coma; strong nucleus; faint broad tail
2.31	(11.0)	(.6)	Johnson 1970 IV 14°, 7.0 yr	Small coma; strong nucleus; short narrow tail
2.35	13		Holmes 1964 X, 1971 b 20°, 7.3 yr	Weak coma; strong nucleus; no tail recently
2.40	10.1	(7)	Van Biesbroeck 1966 III 7°, 12.4 yr	Small coma; strong nucleus; no tail
2.42	12.6	(.3)	Wolf 1 1967 XII 28°, 8.2 yr	Small coma; strong nucleus; no tail
2.44	8.9		Gunn 1969 II 10°, 6.8 yr	Small coma; weak nucleus; small tail
2.53	10.6		Slaughter-Burnham 1970 V 8°, 11.6 yr	Small coma; strong nucleus; faint fan shaped tail
3.08	12.4	(.6)	Whipple 1970 XIV 10°, 8.5 yr	Small coma; strong nucleus; no tail recently

Table 1 PHYSICAL CHARACTERISTICS OF SHORT PERIOD COMETS

Perihelion Distance (AU)	Absolute Magnitude	Size of Coma at 1AU min	Name Recent Designation Inclination and Period	Observed Characteristics
3.94			Van Houten 1961 X 7°, 15.7	Small coma; strong nucleus; no tail
5.47	9.6	1.7	Oterma 1958 IV 2°, 19.4 yr	Medium coma; strong nucleus; narrow tail to .3 mr.
5.78	6.4	12.5	Schwassmann-Wachmann 1 1957 IV 9°, 14.9 yr	Very large coma; strong nucleus; no tail; large outbursts; note unusual orbit (e=.046) and hence large size of comet, it is observed annually at opposition

to Jupiter. If Jupiter approach occurs sufficiently close to cause deflection of the comet's Jovecentric velocity vector by more than 0.5° but less than 5° between two predicted perihelia, the later date is indicated with an # in Table 2. Here, later dates are approximate. For cases in which deflection is predicted to be greater than 5° the close approach date is given approximately and later perihelia are omitted.

The distances from comet to sun and from comet to Earth at perihelion are given next. The final two columns indicate minimum comet to Earth distances during the interval from 100 days before to 100 days after perihelion. These minimum distances enable one to estimate the desirability of the comet at a given perihelion as a mission target. The reason is that acquisition and observation of the target from the Earth are considered essential to mission success, even though on-board acquisition of the target may be an integral phase of the navigation procedure.

Many comets also experience nongravitational forces which are thought to be due to the emission of material from the comet body. It is essential to model such forces for accurate predictions and early recovery in a large telescope. But for the purposes of providing data for the tables given here they are insignificant. For example, perihelion dates due to their effect may be moved as much as a day or two after 20 years, whereas gravitational effects can be many times this amount at the very next perihelion.

There is much variability in the accuracy of perihelia predictions. In the case of comets not seen for a few revolutions, uncertainty is very high. They are included here because if one should have an extremely favorable target opportunity, special searches might be made to locate it.

III <u>Mission Selection Criteria</u>

The major objective of this paper is to develop a list of the comet opportunities which offer the greatest possibilities for scientific return

Table 2

COMET PERIHELIA AND MINIMUM EARTH-COMET DISTANCES PAGE 1

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	T(DAYS)
AREND	1975 MAY 24.6	1.85	2.79	2.94	-100.0
				2.57	100.0
AREND	1983 MAY 22.5	1.86	2.81	2.93	-100.0
				2.60	100.0
AREND	1991 MAY 31.0	1.86	2.63	2.20	100.0
AREND	1999 JUN 5.4*	1.86	2.58	2.12	100.0
AREND	2007 JUN 10.9	1.86	2.53	2.03	100.0
AREND-RIGAU	1978 FEB 2.4	1.44	.97	.83	-62.7
AREND-RIGAU	1984 DEC 1.4	1.45	.68	.56	39.5
AREND-RIGAU	1991 SEP 23.0	1.45	1.80	1.42	100.0
AREND-RIGAU	1998 JUL 23.7*#	1.45	2.38	2.37	24.0
				2.37	100.0
AREND-RIGAU	2005 MAY 23.5	1.45	2.37	2.37	-100.0
				2.34	-32.5
ASHBROOK-JA	1978 AUG 19.0	2.28	1.45	1.30	35.8
ASHBROOK-JA	1986 JAN 24.0	2.31	3.06	2.16	-100.0
ASHBROOK-JA	1993 JUL 14.2*	2.31	2.00	1.39	83.1
ASHBROOK-JA	2001 JAN 1.5	2.31	2.79	1.80	-100.0
ASHBROOK-JA	2008	CLOSE APPROACH TO JUPITER IN APR 2007 POST JUPITER ORBIT NOT AVAILABLE			
BORRELLY	1974 MAY 12.6	1.32	2.30	2.29	-18.2
BORRELLY	1981 FEB 19.9	1.32	1.53	1.41	-100.0
BORRELLY	1987 DEC 18.2	1.36	.50	.48	-11.5
BORRELLY	1994 OCT 28.1*	1.36	.79	.67	37.7
BORRELLY	2001 SEP 7.0	1.36	1.62	1.39	100.0
BORRELLY	2008 JUL 17.9	1.36	2.19	2.13	100.0
BROOKS 2	1974 JAN 4.0	1.84	2.06	1.32	-100.0
BROOKS 2	1980 NOV 25.3	1.85	1.41	.98	-75.7
BROOKS 2	1987 OCT 18.0	1.85	.88	.85	-16.0
BROOKS 2	1994 SEP 7.5*	1.85	1.10	.91	46.1
BROOKS 2	2001 JUL 29.1	1.85	1.76	1.13	100.0
BROOKS 2	2008	CLOSE APPROACH TO JUPITER IN OCT 2005 POST JUPITER ORBIT NOT AVAILABLE			
BRORSEN-MET	1988 NOV 7.5*	.48	.69	.38	-37.2
CHURU-GERAS	1976 APR 7.5*	1.28	2.12	2.20	-100.0
				2.12	-13.2
CHURU-GERAS	1982 NOV 1.0	1.28	.55	.52	32.8
CHURU-GERAS	1989 MAY 21.4	1.28	2.30	2.30	-1.9
CHURU-GERAS	1995 DEC 9.9	1.28	.42	.40	-22.9
CHURU-GERAS	2002 JUN 29.4	1.28	2.19	2.19	5.8
CHURU-GERAS	2009 JAN 16.9	1.28	1.08	.91	-100.0
COMAS SOLA	1978 SEP 24.2	1.87	2.32	1.65	100.0
COMAS SOLA	1987 AUG 18.8	1.83	2.68	2.26	100.0
COMAS SOLA	1996 MAY 28.2*	1.83	2.69	2.26	-100.0
COMAS SOLA	2005 MAR 7.7	1.83	1.62	1.07	-91.0
CROMMELIN	1984 SEP 1.0*	.74	1.41	1.32	-22.1
DANIEL	1978 JUL 8.4	1.66	2.61	2.41	100.0

*Keplerian Orbit Used
#Small Perturbation by Jupiter Previous to Perihelion

COMET PERIHELIA AND MINIMUM EARTH-COMET DISTANCES

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	MIN. EARTH DIST. T(DAYS)
DANIEL	1985 AUG 3.8	1.65	2.41	2.03	100.0
DANIEL	1992 AUG 28.0	1.66	2.15	1.64	100.0
DANIEL	1999*	CLOSE APPROACH TO JUPITER IN FEB 1995 POST JUPITER ORBIT NOT AVAILABLE			
D'ARREST	1976 AUG 12.8	1.16	.15	.15	.0
D'ARREST	1982 SEP 14.1	1.29	.73	.70	-30.2
D'ARREST	1989 FEB 4.0	1.29	2.28	2.28	-2.7
D'ARREST	1995 JUL 7.0	1.30	.70	.66	32.8
D'ARREST	2001 NOV 28.5*	1.30	1.88	1.84	-100.0
				1.84	-36.1
D'ARREST	2008 APR 22.0	1.30	1.83	1.81	32.5
				1.80	100.0
DEVICO-SWIF	1980 JUL 13.9	2.19	2.06	1.34	100.0
DEVICO-SWIF	1987 DEC 7.1	2.18	2.12	1.32	-100.0
DEVICO-SWIF	1995 APR 30.4*	2.18	3.03	3.22	-100.0
				2.37	100.0
DEVICO-SWIF	2002 SEP 21.6	2.18	1.18	1.18	2.6
DEVICO-SWIF	2010 FEB 12.9	2.18	3.03	2.30	-100.0
DU TOIT 1	1974 APR 1.0*	1.28	1.60	1.60	1.9
DU TOIT 1	1989 JAN 13.6	1.28	2.22	2.22	1.9
DU TOIT 1	2003 OCT 29.2	1.28	1.92	2.07	-100.0
				1.92	-.8
DUTOIT-N-DP	1977 JAN 31.3	1.68	2.66	2.73	-100.0
				2.65	40.2
				2.62	100.0
DUTOIT-N-DP	1983 JUN 6.4	1.71	1.30	.91	83.3
DUTOIT-N-DP	1989 OCT 25.4	1.72	1.95	1.34	-100.0
DUTOIT-N-DP	1996 MAR 17.3*	1.72	2.46	2.03	100.0
DUTOIT-N-DP	2002 AUG 8.1	1.72	.75	.72	-19.1
DUTOIT-N-DP	2008 DEC 28.9	1.72	2.63	2.37	-100.0
ENCKE	1974 APR 28.9	.34	.88	.36	45.6
ENCKE	1977 AUG 17.0	.34	1.34	1.22	20.1
ENCKE	1980 DEC 6.5	.34	1.02	.28	-39.1
ENCKE	1984 MAR 27.0	.34	.71	1.66	-100.0
				.63	9.4
				.88	80.9
ENCKE	1987 JUL 17.0	.34	1.27	.89	29.5
ENCKE	1990 NOV 3.6*	.34	1.19	.73	-31.7
ENCKE	1994 FEB 21.3	.34	.66	1.10	-100.0
				.65	-2.5
				1.42	100.0
ENCKE	1997 JUN 11.0	.34	1.12	.42	38.2
ENCKE	2000 SEP 28.7	.34	1.31	1.14	-22.3
ENCKE	2004 JAN 17.4	.34	.78	.51	-23.7
ENCKE	2007 MAY 7.1	.34	.92	.26	45.4
FAYE	1977 FEB 27.8	1.61	2.23	1.79	-100.0
FAYE	1984 JUL 9.9	1.59	2.22	1.87	100.0

*Keplerian Orbit Used

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	T(DAYS)
FAYE	1991 NOV 14.0	1.59	.63	.61	-15.3
FAYE	1999 MAR 20.1*	1.59	2.41	2.11	-100.0
FAYE	2006 JUL 24.2	1.59	2.06	1.64	100.0
FINLAY	1974 JUL 3.9	1.09	1.40	1.38	-15.6
FINLAY	1981 JUN 19.8	1.10	1.57	1.56	-13.0
FINLAY	1988 JUN 5.8	1.09	1.72	1.71	-11.6
FINLAY	1995 MAY 18.9*	1.09	1.89	1.88	-8.9
FINLAY	2002 APR 29.9	1.09	2.00	2.00	-6.4
FINLAY	2009 APR 10.9	1.09	2.07	2.07	-3.9
FORBES	1974 MAY 20.1	1.53	1.12	.83	85.8
FORBES	1980 SEP 25.3	1.48	1.58	1.22	-100.0
FORBES	1987 JAN 2.4	1.47	2.45	2.45	-4.1
FORBES	1993 MAR 15.7	1.45	2.02	1.79	100.0
FORBES	1999 MAY 5.3	1.45	1.30	.98	100.0
FORBES	2005*	CLOSE APPROACH TO JUPITER IN OCT 2001 POST JUPITER ORBIT NOT AVAILABLE			
GALE	1981 OCT 27.9	1.20	1.89	1.89	1.2
GALE	1992 DEC 6.8 *#	1.20	2.15	2.15	1.1
GALE	2004 JAN 16.7	1.20	2.14	2.14	1.3
GIACOBINI-Z	1979 FEB 13.0	1.00	1.83	1.83	.9
GIACOBINI-Z	1985 SEP 4.0	1.03	.49	.49	.5
GIACOBINI-Z	1992 APR 7.3 *	1.03	2.02	2.02	-5.7
GIACOBINI-Z	1998 NOV 9.7	1.03	.66	.66	6.5
GIACOBINI-Z	2005 JUN 13.1	1.03	1.64	1.64	-9.6
GRIGG-SKJEL	1977 APR 10.8	.99	.20	.18	-8.7
GRIGG-SKJEL	1982 MAY 24.0	.99	.36	.32	16.3
GRIGG-SKJEL	1987 JUN 16.0	.99	.88	.83	22.1
GRIGG-SKJEL	1992 JUL 19.9 *	.99	1.36	1.32	19.3
GRIGG-SKJEL	1997 AUG 23.8 #	.99	1.72	1.70	13.8
GRIGG-SKJEL	2002 SEP 27.8	.99	1.93	1.93	7.2
GRIGG-SKJEL	2007 NOV 1.7	.99	1.98	1.98	.3
GUNN	1976 FEB 1.0 *	2.44	3.21	3.44	-100.0
				2.28	100.0
GUNN	1982 DEC 1.0	2.44	3.40	2.77	-100.0
				3.19	100.0
GUNN	1989 SEP 20.1	2.44	2.67	1.65	-100.0
GUNN	1996 JUL 10.3	2.44	1.56	1.44	-31.7
GUNN	2003 APR 30.4	2.44	1.89	1.47	64.0
GUNN	2010 FEB 17.6	2.44	3.02	2.00	100.0
HALLEY	1986 FEB 9.3	.59	1.55	.62	-74.0
				.42	60.4
HARRINGTON2	1974 FEB 17.1	1.60	2.53	2.39	-100.0
HARRINGTON2	1980 DEC 24.0	1.60	2.02	1.53	-100.0
HARRINGTON2	1987 OCT 30.8	1.59	1.14	.82	-78.0
HARRINGTON2	1994 SEP 2.2 *	1.59	.67	.64	18.9
HARRINGTON2	2001 JUL 5.5	1.59	1.55	1.11	100.0
HARRINGTON2	2008	CLOSE APPROACH TO JUPITER IN OCT 2003 POST JUPITER ORBIT NOT AVAILABLE			

*Keplerian Orbit Used
#Small Perturbation by Jupiter Previous to Perihelion

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	T(DAYS)
HARRING-ABE	1976 APR 21.8	1.77	2.12	1.48	-100.0
HARRING-ABE	1983 NOV 29.0	1.78	1.38	.96	76.5
HARRING-ABE	1991 JUL 9.0*	1.78	2.78	2.66	-100.0
HARRING-ABE	1999 FEB 15.8	1.78	1.06	.89	-45.1
HARRING-ABE	2006 SEP 25.6	1.78	2.37	1.75	100.0
HOLMES	1979 FEB 17.0*	2.16	3.09	2.49	-100.0
				3.10	100.0
HOLMES	1986 MAR 7.0	2.16	3.14	2.75	-100.0
				2.93	100.0
HOLMES	1993 MAR 25.0	2.16	3.13	2.97	-100.0
				2.71	100.0
HOLMES	2000 APR 11.0	2.16	3.05	3.13	-100.0
				2.47	100.0
HOLMES	2007 APR 29.0	2.16	2.92	3.23	-100.0
				2.19	100.0
HON-MRK-PAJ	1974 DEC 28.1	.58	.64	1.48	-100.0
				.23	39.0
HON-MRK-PAJ	1980 APR 11.0	.58	1.51	1.42	21.2
HON-MRK-PAJ	1985 MAY 23.9	.54	1.55	1.54	-8.1
HON-MRK-PAJ	1990 SEP 20.0	.55	.85	.17	-43.5
HON-MRK-PAJ	1996 JAN 17.3*	.55	.87	.27	41.0
HON-MRK-PAJ	2001 MAY 15.6	.55	1.56	1.56	-1.0
HON-MRK-PAJ	2006 SEP 11.9	.55	.93	.30	-42.5
JACKSON-NEU	1978 DEC 1.0*	1.43	1.42	1.11	-100.0
JACKSON-NEU	1987 APR 23.5	1.43	2.33	2.32	18.2
JACKSON-NEU	1995 SEP 14.0#	1.43	.47	.46	7.1
JACKSON-NEU	2004 FEB 4.6	1.43	2.24	2.15	-100.0
JOHNSON	1977 JAN 6.0	2.19	3.03	2.27	-100.0
JOHNSON	1983 DEC 2.0	2.31	2.73	1.71	-100.0
JOHNSON	1990 NOV 11.0	2.31	2.41	1.47	-100.0
JOHNSON	1997 OCT 25.6*	2.31	2.14	1.39	-94.4
JOHNSON	2004 OCT 9.3	2.31	1.86	1.35	-72.9
KEARNS-KWEE	1981 DEC 1.4	2.22	1.33	1.26	25.2
KEARNS-KWEE	1990 NOV 24.2	2.22	1.41	1.26	35.8
KEARNS-KWEE	1999 SEP 18.6	2.34	2.47	1.56	100.0
KEARNS-KWEE	2009 FEB 23.5*	2.34	2.27	1.50	-100.0
KLEMOLA	1976 AUG 20.4	1.77	.77	.77	6.4
KLEMOLA	1987 AUG 9.7*#	1.77	.84	.78	23.5
KLEMOLA	1998 JUL 29.0	1.77	.97	.83	40.5
KLEMOLA	2009 JUL 17.4	1.77	1.14	.90	57.6
KOPFF	1977 MAR 10.0	1.57	2.18	1.83	100.0
KOPFF	1983 AUG 13.0	1.57	.96	.75	-64.2
KOPFF	1990 JAN 29.0	1.58	2.50	2.41	100.0
KOPFF	1996 JUL 11.4*	1.58	.57	.57	-9.4
KOPFF	2002 DEC 22.9	1.58	2.54	2.54	-100.0
				2.53	-26.2
KOPFF	2009 JUN 4.4	1.58	.86	.70	53.5

*Keplerian Orbit Used
#Small Perturbation by Jupiter Previous to Perihelion

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	T(DAYS)
NEUJMIN 1	1984 OCT 8.2	1.55	1.04	.87	-58.4
NEUJMIN 1	2002 DEC 24.4*	1.55	2.19	1.97	-100.0
NEUJMIN 2	1976 JUN 18.2	1.28	1.82	1.77	-100.0
				1.81	-20.4
NEUJMIN 2	1981 NOV 12.0	1.27	1.89	1.87	27.5
				1.84	100.0
NEUJMIN 2	1987 APR 2.3	1.27	.64	.58	-55.3
NEUJMIN 2	1992 AUG 22.9*	1.27	2.27	2.27	.2
NEUJMIN 2	1998 JAN 13.4	1.27	.98	.83	100.0
NEUJMIN 2	2003 JUN 5.9	1.27	1.66	1.55	-100.0
NEUJMIN 2	2008 OCT 26.5	1.27	2.05	2.04	16.8
				2.08	100.0
NEUJMIN 3	1982 DEC 6.0	2.06	2.87	2.28	-100.0
NEUJMIN 3	1993 NOV 19.0	2.07	2.71	2.00	-100.0
NEUJMIN 3	2004 OCT 31.1*	2.07	2.47	1.69	-100.0
OTERMA	1983 JUN 18.2	5.47	6.06	6.37	-100.0
				4.69	100.0
OTERMA	2002 NOV 20.9*	5.47	4.65	4.48	-34.1
PERRIN-MRKO	1975 AUG 2.8	1.30	1.75	1.64	100.0
PERRIN-MRKO	1982 MAY 18.0	1.31	2.31	2.31	-1.4
PERRIN-MRKO	1989 MAR 1.0	1.30	1.92	1.86	-100.0
				1.88	-37.9
PERRIN-MRKO	1995 DEC 16.1*	1.30	.77	.72	-37.3
PERRIN-MRKO	2002 OCT 1.2	1.30	.84	.74	58.1
PERRIN-MRKO	2009	CLOSE APPROACH TO JUPITER IN DEC 2006 POST JUPITER ORBIT NOT AVAILABLE			
PONS-WINNEC	1976 NOV 28.7	1.25	2.21	2.21	-5.8
PONS-WINNEC	1983 APR 7.4	1.25	1.29	1.24	100.0
PONS-WINNEC	1989 AUG 19.8	1.26	1.17	1.16	-100.0
				1.14	-25.9
PONS-WINNEC	1996 JAN 6.9*	1.26	2.21	2.21	4.9
PONS-WINNEC	2002 MAY 25.9	1.26	.50	.47	19.9
PONS-WINNEC	2008 OCT 12.0	1.26	1.88	1.87	-18.1
REINMUTH 1	1973 MAR 21.3	1.99	1.55	1.12	-71.2
REINMUTH 1	1980 OCT 29.0	1.98	2.29	1.46	100.0
REINMUTH 1	1988 MAY 13.0	1.95	2.37	1.59	-100.0
REINMUTH 1	1995 NOV 23.3*	1.95	1.86	1.17	100.0
REINMUTH 1	2003 JUN 4.6	1.95	2.64	1.96	-100.0
REINMUTH 2	1974 MAY 8.1	1.94	2.53	1.85	100.0
REINMUTH 2	1981 JAN 29.9	1.94	2.83	2.31	-100.0
REINMUTH 2	1987 OCT 25.7	1.94	1.51	1.04	-77.9
REINMUTH 2	1994 JUL 16.2*	1.94	1.48	1.06	74.9
REINMUTH 2	2001 APR 5.7	1.94	2.82	2.37	100.0
REINMUTH 2	2007 DEC 26.2	1.94	2.48	1.72	-100.0
SCHAUMASSE	1976 SEP 5.1	1.20	2.15	2.15	2.7
SCHAUMASSE	1984 DEC 7.3	1.21	1.16	1.16	7.5
				1.12	100.0

*Keplerian Orbit Used

COMET PERIHELIA AND MINIMUM EARTH-COMET DISTANCES PAGE 6

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	T(DAYS)
SCHAUMASSE	1993 MAR 7.0	1.21	.61	.59	-45.6
SCHAUMASSE	2001 JUN 8.5*	1.21	1.92	2.08	-100.0
				1.92	1.1
SCHAUMASSE	2009 SEP 10.0	1.21	2.14	2.14	3.1
SCHWA-WACH1	1974 FEB 15.1	5.45	6.43	5.36	-100.0
				5.69	100.0
SCHWA-WACH1	1989 AUG 30.0	5.78	4.86	4.79	22.2
SCHWA-WACH1	2004 AUG 3.8*	5.78	5.13	4.79	50.2
SCHWA-WACH2	1974 SEP 12.3	2.14	2.94	2.15	100.0
SCHWA-WACH2	1981 MAR 17.0	2.13	1.72	1.22	-73.6
SCHWA-WACH2	1987 AUG 30.5	2.07	2.97	3.14	-100.0
				2.35	100.0
SCHWA-WACH2	1994 JAN 19.3*	2.07	1.09	1.09	7.7
SCHWA-WACH2	2000	CLOSE APPROACH TO JUPITER IN MAR 1997 POST JUPITER ORBIT NOT AVAILABLE			
SCHWA-WACH3	1974 MAR 14.6	.94	1.41	1.35	-21.3
SCHWA-WACH3	1979 JUL 27.2	.91	.61	1.00	-100.0
				.44	34.7
SCHWA-WACH3	1984 NOV 22.1*	.91	1.84	1.83	9.2
SCHWA-WACH3	1990 MAR 20.9	.91	1.32	1.25	-24.3
SCHWA-WACH3	1995 JUL 17.7	.91	.46	.30	33.9
SCHWA-WACH3	2000 NOV 12.5	.91	1.80	1.78	12.1
SCHWA-WACH3	2006 MAR 11.3	.91	1.43	1.37	-22.0
SHAJN-SCHAL	1979 JAN 1.0*	2.23	2.23	1.37	-100.0
SHAJN-SCHAL	1986 APR 1.0	2.23	3.21	2.72	-100.0
				3.09	100.0
SHAJN-SCHAL	1993 JUL 7.9	2.23	2.56	1.63	100.0
SHAJN-SCHAL	2000 OCT 13.9	2.23	1.23	1.23	1.5
SHAJN-SCHAL	2008 JAN 20.8	2.23	2.54	1.57	-100.0
SLAUGH-BURN	1981 NOV 19.0	2.53	1.71	1.56	-35.8
SLAUGH-BURN	1993 JUN 19.5*	2.53	3.19	2.25	100.0
SLAUGH-BURN	2005 JAN 18.0	2.53	2.68	1.71	-100.0
STEPHAN-OTE	1980 DEC 1.0	1.59	.64	.63	10.1
SWIFT-GEHRL	1981 NOV 27.4*	1.36	.67	.59	46.3
SWIFT-GEHRL	1991 FEB 28.0	1.36	.99	1.97	-100.0
				2.01	-32.6
SWIFT-GEHRL	2000 JUN 2.0	1.36	2.28	2.27	6.8
SWIFT-GEHRL	2009 SEP 3.9	1.36	1.19	1.00	100.0
TEMPEL 1	1976 JAN 11.0	1.50	2.32	2.13	100.0
TEMPEL 1	1983 JUL 9.8	1.49	.95	.74	-69.6
TEMPEL 1	1989 JAN 4.5	1.50	2.36	2.22	100.0
TEMPEL 1	1994 JUL 6.8*	1.50	.91	.72	-64.5
TEMPEL 1	2000 JAN 6.0	1.50	2.36	2.21	100.0
TEMPEL 1	2005 JUL 7.2	1.50	.92	.72	-65.7
TEMPEL 2	1972 NOV 15.0	1.36	1.85	1.66	-100.0
TEMPEL 2	1978 FEB 20.7	1.37	2.32	2.31	11.4
TEMPEL 2	1983 JUN 1.5	1.38	1.24	1.00	100.0

*Keplerian Orbit Used

COMET PERIHELIA AND MINIMUM EARTH-COMET DISTANCES

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	(DAYS)
TEMPEL 2	1988 SEP 16.7	1.38	.95	.77	-80.2
TEMPEL 2	1994 MAR 16.8	1.48	2.31	2.18	100.0
TEMPEL 2	1999 SEP 6.6*	1.48	.81	.64	-55.3
TEMPEL 2	2005 FEB 26.5	1.48	2.41	2.39	33.2
TEMPEL-SWIF	1976 MAY 25.7	1.60	2.57	2.50	100.0
TEMPEL-SWIF	1982 OCT 22.0	1.60	.71	.65	26.1
TEMPEL-SWIF	1989 MAR 24.0*	1.61	2.44	2.14	-100.0
TEMPEL-SWIF	1995 AUG 24.0	1.61	1.65	1.12	100.0
TEMPEL-SWIF	2002 JAN 24.0	1.61	1.71	1.18	-100.0
TEMPEL-SWIF	2008 JUN 26.0	1.61	2.39	2.08	100.0
TEMPEL-TUTL	1998 FEB 27.3	.98	1.46	.35	-41.1
				1.91	100.0
TSUCHINSHN1	1978 APR 1.0*	1.49	1.52	1.08	-100.0
TSUCHINSHN1	1985 JAN 1.0	1.49	.65	.59	28.5
TSUCHINSHN1	1991 AUG 22.0	1.49	2.42	2.36	100.0
TSUCHINSHN1	1998 APR 11.0	1.49	1.67	1.24	-100.0
TSUCHINSHN1	2004 NOV 29.1	1.49	1.18	.88	67.8
TSUCHINSHN2	1978 AUG 1.0*	1.77	2.79	2.73	-100.0
				2.75	100.0
TSUCHINSHN2	1985 MAY 1.0	1.77	2.03	1.34	-100.0
TSUCHINSHN2	1992 FEB 17.5	1.77	88	.81	-25.9
TSUCHINSHN2	1998 DEC 6.0	1.77	1.50	1.00	88.7
TSUCHINSHN2	2005 SEP 23.6	1.77	2.54	2.03	100.0
TUTTLE	1980 DEC 14.7	1.01	.55	.49	-12.1
TUTTLE	1994 JUN 26.0	1.01	1.98	1.93	25.8
TUTTLE	2008 JAN 11.3*#	1.01	.38	.08	-19.7
TUTLGIAKRES	1973 MAY 29.9	1.15	.85	.86	-91.5
				.85	5.3
TUTLGIAKRES	1978 DEC 25.1	1.12	1.72	1.72	-2.4
TUTLGIAKRES	1984 JUL 27.4	1.12	1.66	1.86	-100.0
				1.65	10.5
TUTLGIAKRES	1990 FEB 6.6	1.07	1.11	1.09	-15.4
				1.27	100.0
TUTLGIAKRES	1995 JUL 25.6*	1.07	1.59	1.87	-100.0
				1.57	15.9
TUTLGIAKRES	2001 JAN 9.5	1.07	1.49	1.48	-10.5
TUTLGIAKRES	2006 JUN 27.5	1.07	1.24	1.42	-100.0
				1.21	20.3
VAISALA 1	1982 AUG 1.0	1.80	2.53	2.09	-100.0
VAISALA 1	1993 MAY 27.0	1.80	1.63	1.11	-100.0
VAISALA 1	2004 MAR 22.0*	1.80	.82	.82	.3
VAN BIESBRO	1978 DEC 3.0	2.40	3.26	2.57	-100.0
				3.38	100.0
VAN BIESBRO	1991 APR 22.8*	2.40	2.28	1.53	100.0
VAN BIESBRO	2003 SEP 10.6	2.40	2.15	1.51	-88.5
VAN HOUTEN	1977 JAN 1.0*	3.94	3.59	2.96	-71.3
VAN HOUTEN	1992	CLOSE APPROACH TO JUPITER IN FEB 1979 POST JUPITER ORBIT NOT AVAILABLE			

*Keplerian Orbit Used
#Small Perturbation by Jupiter Previous to Perihelion

COMET PERIHELIA AND MINIMUM EARTH-COMET DISTANCES PAGE 8

NAME	PERIHELION DATE	SUN DIST. (AU)	EARTH DIST. (AU)	MIN. EARTH DIST. D(AU)	T(DAYS)
WESTPHAL	1976 JAN 3.9	1.26	1.30	1.10	-92.1
WHIPPLE	1978 MAR 27.5	2.47	3.45	2.83	-100.0
				3.24	100.0
WHIPPLE	1986 JUN 25.0	3.08	3.57	4.11	-100.0
				2.38	100.0
WHIPPLE	1994 DEC 21.6*	3.08	2.81	2.10	-80.2
WHIPPLE	2003 JUN 19.2	3.08	3.65	4.09	-100.0
				2.46	100.0
WILD	1973 JUL 2.0*	1.98	2.55	1.89	-100.0
WILD	1986 SEP 1.0	1.98	2.98	2.79	-100.0
				2.93	100.0
WILD	1999 DEC 16.9	1.98	2.10	1.36	100.0
WIRTANEN	1974 JUL 5.6	1.26	2.21	2.21	3.5
WIRTANEN	1980 MAY 22.9	1.26	2.25	2.25	-4.5
WIRTANEN	1986 MAR 19.7	1.08	1.60	1.80	-100.0
				1.60	7.2
WIRTANEN	1991 SEP 21.1	1.08	1.35	1.34	-12.0
				1.49	100.0
WIRTANEN	1997 MAR 14.4	1.06	1.52	1.73	-100.0
				1.51	10.2
WIRTANEN	2002 AUG 28.1*	1.06	1.63	1.62	-11.7
WIRTANEN	2008 FEB 10.7	1.06	1.07	1.20	-100.0
				1.05	13.2
WOLF 1	1976 JAN 25.0	2.50	3.07	2.05	-100.0
WOLF 1	1984 MAY 31.0	2.41	3.03	2.03	100.0
WOLF 1	1992 AUG 21.0	2.41	1.78	1.45	52.1
WOLF 1	2000 NOV 10.4*	2.41	1.79	1.50	-49.8
WOLF 1	2009 JAN 30.9	2.41	3.06	2.08	-100.0
WOLF-HARRIN	1978 MAR 15.0	1.61	1.94	1.38	-100.0
WOLF-HARRIN	1984 SEP 22.0	1.61	1.78	1.26	100.0
WOLF-HARRIN	1991 APR 4.0	1.61	2.20	1.71	-100.0
WOLF-HARRIN	1997 OCT 15.1*	1.61	1.40	1.00	89.9
WOLF-HARRIN	2004 APR 27.3	1.61	2.44	2.09	-100.0

*Keplerian Orbit Used

as well as being reasonable in regard to spacecraft and launch vehicle requirements. In order to obtain standards by which this may be done mission selection criteria need to be examined. Several authors (Lüst, 1969; Roberts, 1971, NASA, 1972; Arrhenius, et.al., 1973) have discussed this subject with only minor variations among the lists presented. The criteria are conveniently divided into the two categories mentioned and are listed in Table 3. There is no implication as to relative importance and they are discussed below in the order given in the table.

Table 3

Mission Selection Criteria

A. Scientific
   1. Certainty and Time of Return of the Comet
   2. Scientific Information Return
      a. Flyby Velocity
      b. Comet Characteristics
B. Launch Vehicle and Spacecraft Performance
   1. Perihelion Location and Acquisition
   2. Total ΔV and Launch Vehicle Requirements
   3. Flight Time
   4. Navigational Problems

Criterion A.1 It is clear from the discussion of the previous section, that the efforts of many persons in recent years have resulted in the recovery of several "lost" comets. Now it is safe to assume that, barring unpredictable comet disintegrations, the return and reacquisition of a fairly bright periodic comet will occur as predicted. Thus the time of return is only required to match that of the projected mission to be considered as far as this point alone is considered.

Criterion A.2 The flyby velocity is an important consideration in scientific data return since it affects both the duration of the observations of the comet and their content. The slower the flyby the greater the time for navigation to a close approach, the better the molecular constitutents can be determined without being perturbed by the measuring device, and the greater the detail in structure that can be resolved. Thus the data return from a slow flyby with a relative velocity of 5 km/sec or less can be expected to be significantly greater than that from a fast flyby at 10 km/sec or more. A flyby mission is in fact more important as a precursor mission for comet than for a planet since there is so much uncertainty regarding the comet environment (NASA 1972). Thus a flyby mission (the slower the better) would enable us materially to improve the design of experimentation for a subsequent rendezvous mission.

The existence of considerable scientific interest in a mission is essential to its being carried through. Unless a comet suggested as a target has given some indication of being active in several ways as it approaches perihelion, it is doubtful if it is a viable target. It would be impossible to arrange the comets in an order of scientific interest that would be approved by many comet scientists. Rather it is suggested that only three categories of interest be established on the basis of the data in Table 1. The three groups are labeled here as comets of Primary Interest, comets of Secondary Interest, and comets of Low Interest with the selection criteria as follows.

Primary Interest: Those with large coma and absolute magnitude brighter than 12, and those with medium (or larger) coma and observed tail in recent years or absolute magnitude brighter than 10.5.

Secondary Interest: Those remaining with medium (or larger coma) and those with small coma and observed tail or absolute magnitude brighter than 13.

Low Interest: All others, but including those comets of any size not detected during their last five predicted returns.

The distribution of comets into these categories is given in Tables 5, 6, and 7 where the comets in each are arranged alphabetically.

<u>Criterion B.1</u> There are two important aspects of the mission with regard to the location of the perihelion, and thus also with regard to the location of the spacecraft during the encounter. These deal with the operation of the spacecraft in the solar environment with the activity of the comet. A third concern related to perihelion location is the problem of acquisition of the comet from Earth before the spacecraft encounters the comet.

The perihelion of Encke, which is much discussed as a target for a comet mission (Atkins and Moore, 1973), is at .34 AU from the Sun where the solar heat and particle fluxes are nearly ten times the values at the Earth. The next closest perihelia to be considered are those of Honda-Mrkos-Padjusakova and Halley at about .6 AU. Careful design of a spacecraft is essential if it is to survive the solar radiation during a perihelion passage with one of these comets.

The activity of a comet increases generally as perihelion is approached and for this reason practically all comet missions that are seriously considered are planned to arrive at the comet about 50 days before perihelion (except for cases like Schwassmann-Wachmann 1 where the comet is in a nearly circular orbit). Thus for a rendezvous mission the comet could be observed for a period of several months as it passes through its most active state.

The reacquisition of a comet from Earth as it approaches a perihelion passage clearly depends on the Earth-comet distance during the approach. Such observations are essential for navigation even if the spacecraft is capable of acquiring the comet directly, and they are also essential so that Earth based observations can be correlated with the spacecraft observations. Several investigators (Narin and Pierce 1964, 1965; Friedlander 1970) have examined sighting conditions for many predicted perihelia and have estimated recovery possibilities and dates. In this discussion a simple, rather crude method will be used which deals only with Earth-comet distance during the near perihelion. This condition is that the Earth-comet distance be reasonably small during most of the 100 days before perihelion. For comets with perihelion distances under 1.5 AU this distance is taken to be less than 1.5 AU, whereas for comets with larger perihelion distances it is increased to the perihelion distance. It is to be noted that this criterion requires that the Earth and Comet be in the same general direction from the sun and consequently the elongation of the comet (the comet-Earth-Sun angle) will be fairly large for all cases (except when the comet perihelion is less than 1 AU). The minimum values of this angle over the interval $T_p \pm 100$ days for the satisfactory perihelia are generally in the range 50-100°. Thus Earth based acquisition and observation of the comet may be expected to be feasible during the encounter phase of the mission opportunities selected. As may be expected this distance criterion is less stringent than the sighting criteria of Friedlander (1970). No comets listed as good or fair by Friedlander are missed.

Criteria B.2, B.3, and B.4 In the selection of a mission it is essential to place limitations upon total velocity required, the launch vehicle, the duration of the mission, and the navigational uncertainties. In this paper, however, it is the aim to categorize single comet missions only on the basis of estimated scientific interest and return and on comet availability near the Earth. Spacecraft performance summaries and trajectories will be the subject of a separate paper.

IV Mission Types

This paper deals with missions to a single comet, which, as mentioned above, is to be encountered near its perihelion. The types of mission (Manning, 1970; Friedlander 1970, 1971) that are possible are briefly described here and are listed in Table 4 along with pertinent orbital constraints.

The most straightforward mission is the ballistic fast flyby or one impulse mission. In searching for this type of mission opportunity, one procedure is simply to determine those comet perihelia in which the comet passes close to Earth, it being assumed that in a flight time of less than a year a spacecraft can readily be launched to arrive at any specific point near the Earth. Table 8 below contains a chronological list of the perihelia which approach the Earth within .75 AU. Longer flight times to more distant points can be envisaged as similar to ballistic flights to Mars or to Jupiter.

On the other hand, slow flyby and rendezvous missions to comets require long flight times because of the fact that comet orbits are quite elliptical, usually significantly inclined to the eclipitc and of considerably greater energy (period or semi-major axis) than that of the Earth. The trajectory modifications after launch into the solar system can be provided by impulses from chemical rocket engines, by low thrust electric propulsion systems, or by a gravity turn at Jupiter or Saturn coupled with a ballistic or low thrust engine for providing the final change in velocity. Modest gravity turns are also available at Venus or Mars but only the Venus encounter has been proposed to date (Bender et. al., 1973). All such trajectories are rather similar in that the spacecraft travels fairly far out in the solar system to a point near a node of the comet's orbit, where the inclination of the spacecraft's orbit to the ecliptic can be changed economically to match that of the comet before the spacecraft turns back toward the sun to encounter the comet. Except for the Jupiter flyby type the total flight time can be varied by as much as a year by varying the aphelion of the trajectory. Consequently, at every perihelion a comet is available as a rendezvous target for missions using the multi-impulse ballistic mode or the solar electric flight mode. But for Jupiter gravity assist missions two timing or orbit conditions must be met:

a. The flyby of Jupiter must occur when Jupiter is close to the comet orbit plane in order that the orbits of spacecraft and comet shall be practically in the same plane for an economical final impulse to rendezvous, and

b. The perihelion of the comet should be of the order of 180° central angle from the Jupiter passage and of the order of two years later assuming it is at a solar distance of the order of 1 AU.

Perihelia for which these conditions are approximately met (angles from 130° to 260° away and times from 0.3 yr. to 4.5 yrs.) are indicated with an underline of the perihelion year in Table 2. The table of Jupiter gravity assist possiblities given by Manning (1970 Table 1) is less extensive than these results. Here no estimate of the usefulness of the Jupiter gravity assist trajectories is made.

Table 4 Summary of Orbit Restrictions for Comet Mission

Mission Type	Range of Flight Times for Prograde Comets (Years)	Orbital Constraints
Ballistic		
Flyby, Fast Rel. Vel.>5 km/s		
One impulse (the launch)	.3 - 1	Comet comes fairly close to Earth near perihelion
Flyby, Slow Rel. Vel.<5 km/s		
Two-impulse (2)	2 - 4	None
Jupiter gravity assist	3 - 5	Jupiter in prcper location
Rendezvous		
Three-impulse	2 - 4	None
Jupiter gravity assist	3 - 5	Jupiter in proper location
Low Thrust; Solar or Nuclear Electric		
Flyby, Slow	1 - 3	None
Rendezvous	2 - 4	None

V Missions Selected

The application of criteria A.2 and B.1 to the comet perihelia listed in Table 2 yields three lists of comet missions which can be categorized as the most promising missions for each group of comets. The list for the comets of primary interest is given in Table 5 which therefore contains the most important single comet mission possibilities to the short period comets for the next 35 years. There are fifty-seven missions suggested on this basis including the eleven predicted returns of the comet Encke and the return of Halley in 1986.

Tables 6 and 7 contain the single comet mission suggestions for comets of secondary and low interest respectively. There are 43 secondary interest missions and 42 low interest missions.

Tables 5, 6 and 7 include a column indicating whether (P) or not (N) a Jupiter gravity assist mission might be a possibility on the basis of the timing criteria mentioned in section III. It is to be noted that for all the perihelia selected, any one of the other types of missions discussed in section III is possible.

The final table presented (Table 8) is a chronological list of comet perihelia in which only those comets with trajectories that are predicted to pass within .75 AU of the Earth are given. All the comets were used and their interest category is indicated.

This list includes 51 cases of perihelia for possible missions all of which are included in Tables 5, 6, and 7. Actually it includes the majority of opportunities for which some trajectory data exist. Thus it provides a convenient chronological list of possibilities. It indicates in addition that there will be close approaches of four comets under .2 AU in the thirty six years. Two of these, namely d'Arrest in 1976 at .15 AU and Grigg-Skjellerup at .18 AU in 1977, will occur in the near future and it is suggested that Earth based radar might be used to attempt to reflect signals off these comets in order to estimate the size of the nucleus.

VI Summary and Conclusions

Sixty-five known short period comets have been grouped into three categories of mission targets on the basis of size, activity, and unusual features. There are twenty-two which are classified as targets of primary interest, 23 as targets of secondary interest, and 20 as targets of low interest. Predictions for the returns of all these comets through the year 2010 have been made and the Earth-Sun-comet geometry briefly investigated for each case. Since a passage reasonably close to the Earth enhances the observability of one of these comets and since observing the comet from the Earth is considered a necessity for a mission to the comet, the perihelion passages are easily separated into two categories. By combining these two criteria the three Tables (Tables 5, 6, and 7) of mission possibilities are produced. The first of these, which contains the fifty-seven most important single comet mission possibilities among the primary interest short period comets is the major shopping list for single comet missions. There are 43 further possibilities among the secondary interest comets and 42 among the low interest comets.

Table 5 PRIMARY INTEREST COMETS

PERIHELIA FOR THE MOST PROMISING MISSIONS

NAME	DATE PERIHEL			JGA	ORBITAL ELEMENTS					
					Q(AU)	E	I	NODE	AR.PER	PERIOD(Y)
ASHBROOK-JA	1978	AUG	19.0	N	2.28	.40	12.5	2.1	349.0	7.4
ASHBROOK-JA	1993	JUL	14.2	P	2.28	.40	12.5	2.2	348.8	7.4
BRORSEN-MET	1988	NOV	7.5	P	.48	.97	19.2	311.2	129.5	69.1
CHURU-GERAS	1982	NOV	1.0	P	1.28	.63	7.1	50.4	11.2	6.6
CHURU-GERAS	1995	DEC	9.9	P	1.28	.63	7.1	50.4	11.2	6.6
CHURU-GERAS	2009	JAN	16.9	P	1.28	.63	7.1	50.4	11.2	6.6
COMAS SOLA	2005	MAR	7.7	N	1.83	.57	13.0	60.4	45.5	8.8
D'ARREST	1976	AUG	12.8	N	1.16	.66	16.7	141.4	178.9	6.2
D'ARREST	1982	SEP	14.1	P	1.29	.62	19.4	138.9	177.0	6.4
D'ARREST	1995	JUL	7.0	P	1.30	.62	19.6	138.8	177.0	6.4
ENCKE	1974	APR	28.9	N	.34	.85	12.0	334.2	185.9	3.3
ENCKE	1977	AUG	17.0	P	.34	.85	11.9	334.2	186.0	3.3
ENCKE	1980	DEC	6.5	N	.34	.85	11.9	334.2	186.0	3.3
ENCKE	1984	MAR	27.0	N	.34	.85	11.9	334.2	186.0	3.3
ENCKE	1987	JUL	17.0	P	.34	.85	11.9	334.2	186.0	3.3
ENCKE	1990	NOV	3.6	N	.34	.85	11.9	334.2	186.0	3.3
ENCKE	1994	FEB	21.3	N	.34	.85	11.9	334.2	186.0	3.3
ENCKE	1997	JUN	11.0	N	.34	.85	11.9	334.2	186.0	3.3
ENCKE	2000	SEP	28.7	P	.34	.85	11.9	334.2	186.0	3.3
ENCKE	2004	JAN	17.4	N	.34	.85	11.9	334.2	186.0	3.3
ENCKE	2007	MAY	7.1	N	.34	.85	11.9	334.2	186.0	3.3
FAYE	1991	NOV	14.0	P	1.59	.58	9.1	199.0	203.8	7.3
GIACOBINI-Z	1985	SEP	4.0	P	1.03	.71	31.9	194.7	172.5	6.6
GIACOBINI-Z	1998	NOV	9.7	N	1.03	.71	31.9	194.7	172.5	6.6
HALLEY	1986	FEB	9.3	P	.59	.97	162.2	58.2	111.9	76.0
HON-MRK-PAJ	1974	DEC	28.1	P	.58	.81	13.1	233.0	184.6	5.3
HON-MRK-PAJ	1990	SEP	20.0	N	.54	.82	4.2	88.6	325.8	5.3
HON-MRK-PAJ	1996	JAN	17.3	N	.54	.82	4.2	88.6	325.8	5.3
HON-MRK-PAJ	2006	SEP	11.9	N	.54	.82	4.2	88.6	325.8	5.3
KEARNS-KWEE	1981	DEC	1.4	N	2.22	.49	9.0	315.3	131.4	9.0
KEARNS-KWEE	1990	NOV	24.2	N	2.22	.49	9.0	315.0	131.8	9.0
KEARNS-KWEE	1999	SEP	18.6	P	2.34	.48	9.3	312.3	127.6	9.4
KEARNS-KWEE	2009	FEB	23.5	N	2.34	.48	9.3	312.3	127.6	9.4
KOPFF	1983	AUG	13.0	P	1.57	.55	4.7	120.3	162.8	6.4
KOPFF	1996	JUL	11.4	N	1.57	.55	4.7	120.3	162.8	6.4
KOPFF	2009	JUN	4.4	N	1.57	.55	4.7	120.3	162.8	6.4
OTERMA	1983	JUN	18.2	P	5.47	.24	1.9	331.2	55.9	19.4
OTERMA	2002	NOV	20.9	P	5.47	.24	1.9	331.2	55.9	19.4
SCHAUMASSE	1984	DEC	7.3	P	1.21	.70	11.8	80.4	57.4	8.3
SCHAUMASSE	1993	MAR	7.0	N	1.21	.70	11.8	80.4	57.4	8.3
SCHWA-WACH1	1974	FEB	15.1	N	5.45	.11	9.7	319.6	14.5	15.0
SCHWA-WACH1	1989	AUG	30.0	N	5.78	.05	9.3	312.3	45.0	14.9
SCHWA-WACH2	1981	MAR	17.0	N	2.14	.39	3.7	125.9	357.5	6.5
SCHWA-WACH2	1994	JAN	19.3	N	2.07	.40	3.8	125.7	357.9	6.4
SHAJN-SCHAL	1979	JAN	1.0	N	2.23	.41	6.2	167.3	215.1	7.3
SHAJN-SCHAL	1993	JUL	7.9	P	2.23	.41	6.2	167.3	215.1	7.3

Table 5 PRIMARY INTEREST COMETS

PERIHELIA FOR THE MOST PROMISING MISSIONS

NAME	DATE PERIHEL	JGA	ORBITAL ELEMENTS Q(AU)	E	I	NODE	AR.PER	PERIOD(Y)
SHAJN-SCHAL	2000 OCT 13.9	N	2.23	.41	6.2	167.3	215.1	7.3
SHAJN-SCHAL	2008 JAN 20.8	P	2.23	.41	6.2	167.3	215.1	7.3
STEPHAN-OTE	1980 DEC 1.0	N	1.60	.86	17.9	78.6	358.4	39.0
TEMPEL 2	1983 JUN 1.5	P	1.38	.54	12.4	119.2	190.9	5.3
TEMPEL 2	1988 SEP 16.7	N	1.38	.54	12.4	119.1	191.0	5.3
TEMPEL 2	1999 SEP 6.6	N	1.48	.52	12.0	117.6	194.9	5.5
TUTTLE	1980 DEC 14.7	N	1.01	.82	54.5	269.9	206.9	13.7
TUTTLE	2008 JAN 11.3	N	1.01	.82	54.7	269.9	206.6	13.5
TUTLGIAKRES	1990 FEB 6.6	P	1.07	.66	9.2	141.0	61.5	5.5
TUTLGIAKRES	2006 JUN 27.5	N	1.07	.66	9.2	141.0	61.5	5.5
WESTPHAL	1976 JAN 3.9	N	1.26	.92	40.8	347.3	57.0	63.0

Table 6 SECONDARY INTEREST COMETS PAGE 3

PERIHELIA FOR THE MOST PROMISING MISSIONS

NAME	DATE PERIHEL	JGA	ORBITAL ELEMENTS Q(AU)	E	I	NODE	AR.PER	PERIOD(Y)
AREND	NO SATISFACTORY APPROACHES							
AREND-RIGAU	1978 FEB 2.4	N	1.44	.60	17.9	121.5	329.0	6.8
AREND-RIGAU	1984 DEC 1.4	N	1.45	.60	17.8	121.6	328.9	6.8
BORRELLY	1987 DEC 18.2	P	1.36	.62	30.3	74.7	353.3	6.9
BORRELLY	1994 OCT 28.1	N	1.36	.62	30.3	74.7	353.3	6.9
CROMMELIN	1984 SEP 1.0	P	.74	.92	28.9	250.4	196.0	27.9
DEVICO-SWIF	2002 SEP 21.6	N	2.18	.43	6.1	358.5	1.9	7.4
FINLAY	1974 JUL 3.9	N	1.10	.70	3.6	41.8	322.1	7.0
GALE	NO SATISFACTORY APPROACHES							
GRIGG-SKJEL	1977 APR 10.8	P	.99	.66	21.1	212.6	359.3	5.1
GRIGG-SKJEL	1982 MAY 14.0	N	.99	.67	21.1	212.6	359.3	5.1
GRIGG-SKJEL	1987 JUN 16.0	N	.99	.67	21.1	212.6	359.3	5.1
GRIGG-SKJEL	1992 JUL 19.9	P	.99	.67	21.1	212.6	359.3	5.1
GRIGG-SKJEL	1997 AUG 23.8	N	.99	.67	21.1	212.6	359.3	5.1
GUNN	1996 JUL 10.3	N	2.44	.32	10.4	68.0	197.2	6.8
GUNN	2003 APR 30.4	N	2.44	.32	10.4	68.0	197.2	6.8
HARRINGTON2	1987 OCT 30.8	N	1.60	.56	8.7	118.9	233.0	6.8
HARRINGTON2	1994 SEP 2.2	P	1.60	.56	8.7	118.9	233.0	6.8
HARRINGTON2	2001 JUL 5.5	N	1.60	.56	8.7	118.9	233.0	6.8
JACKSON-NEU	1978 DEC 1.0	N	1.43	.65	14.0	163.2	196.3	8.4
JACKSON-NEU	1995 SEP 14.0	P	1.43	.65	14.0	163.2	196.3	8.4
JOHNSON	2004 OCT 9.3	P	2.31	.37	13.7	116.7	208.4	7.0
NEUJMIN 1	1984 OCT 8.2	P	1.55	.78	14.2	346.3	346.8	18.2
PONS-WINNEC	1983 APR 7.4	N	1.25	.63	22.3	92.7	172.3	6.4
PONS-WINNEC	1989 AUG 19.8	N	1.26	.63	22.3	92.7	172.3	6.4
PONS-WINNEC	2002 MAY 25.9	P	1.26	.63	22.3	92.7	172.3	6.4
REINMUTH 2	1987 OCT 25.7	N	1.94	.46	7.0	296.0	45.5	6.7
REINMUTH 2	1994 JUL 16.2	P	1.94	.46	7.0	296.0	45.5	6.7
SLAUGH-BURN	1981 NOV 19.0	P	2.53	.51	8.2	345.9	44.0	11.6
SLAUGH-BURN	2005 JAN 18.0	P	2.53	.51	8.2	345.9	44.0	11.6
SWIFT-GEHRL	1981 NOV 27.4	N	1.36	.69	9.2	314.0	84.5	9.3
SWIFT-GEHRL	1991 FEB 28.0	N	1.36	.69	9.2	314.0	84.5	9.3
SWIFT-GEHRL	2009 SEP 3.9	N	1.36	.69	9.2	314.0	84.5	9.3
TEMPEL 1	1983 JUL 9.8	N	1.49	.52	10.6	68.3	179.0	5.5
TEMPEL 1	1994 JUL 6.8	N	1.50	.52	10.5	68.3	179.0	5.5
TSUCHINSHN2	1992 FEB 17.5	N	1.77	.51	6.7	287.6	203.2	6.8
TSUCHINSHN2	1998 DEC 6.0	P	1.77	.51	6.7	287.6	203.2	6.8
VAN BIESBRO	1991 APR 22.8	N	2.40	.55	6.6	148.6	134.3	12.4
VAN BIESBRO	2003 SEP 10.6	N	2.40	.55	6.6	148.6	134.3	12.4
WHIPPLE	1994 DEC 21.6	P	3.08	.26	9.9	181.8	202.0	8.5
WILD	NO SATISFACTORY APPROACHES							
WOLF-HARRIN	1984 SEP 22.0	P	1.61	.54	18.4	254.2	186.9	6.5
WOLF-HARRIN	1997 OCT 15.1	P	1.61	.54	18.4	254.2	186.9	6.5

Table 7 LOW INTEREST COMETS
PERIHELIA FOR THE MOST PROMISING MISSIONS

NAME	DATE PERIHEL			JGA	ORBITAL ELEMENTS					
					Q(AU)	E	I	NODE	AR.PER	PERIOD(Y)
BROOKS 2	1980	NOV	25.3	N	1.85	.49	5.5	176.2	198.2	6.9
BROOKS 2	1987	OCT	18.0	N	1.85	.49	5.6	176.2	198.1	6.9
BROOKS 2	1994	SEP	7.5	P	1.85	.49	5.6	176.2	198.1	6.9
BROOKS 2	2001	JUL	29.1	N	1.85	.49	5.6	176.2	198.1	6.9
DANIEL	NO SATISFACTORY APPROACHES									
DU TOIT 1	NO SATISFACTORY APPROACHES									
DUTOIT-N-DP	1983	JUN	6.4	N	1.71	.50	2.9	187.1	116.6	6.4
DUTOIT-N-DP	2002	AUG	8.[illegible]	N	1.72	.50	2.9	187.0	116.7	6.4
FORBES	1974	MAY	20.1	N	1.53	.56	4.6	25.2	259.9	6.4
FORBES	1999	MAY	5.3	N	1.45	.57	7.2	333.6	310.6	6.1
HARRING-ABE	1983	NOV	29.0	N	1.78	.54	10.2	336.7	138.6	7.6
HARRING-ABE	1999	FEB	15.8	P	1.78	.54	10.2	336.7	138.6	7.6
HOLMES	2000	OCT	10.5	N	2.16	.41	19.2	327.5	23.5	7.0
KLEMOLA	1976	AUG	20.4	N	1.77	.64	10.6	181.6	148.9	11.0
KLEMOLA	1987	AUG	9.7	N	1.77	.64	10.6	181.6	148.9	11.0
KLEMOLA	1998	JUL	29.0	N	1.77	.64	10.6	181.6	148.9	11.0
KLEMOLA	2009	JUL	17.4	P	1.77	.64	10.6	181.6	148.9	11.0
NEUJMIN 2	1987	APR	2.3	P	1.27	.59	5.4	307.2	214.9	5.4
NEUJMIN 2	1998	JAN	13.4	P	1.27	.59	5.4	307.2	214.9	5.4
NEUJMIN 3	NO SATISFACTORY APPROACHES									
PERRIN-MRKO	1995	DEC	16.1	P	1.31	.64	17.8	239.9	166.6	6.8
PERRIN-MRKO	2002	OCT	1.2	N	1.31	.64	17.8	239.9	166.6	6.8
REINMUTH 1	1995	NOV	23.3	N	1.98	.49	8.3	121.1	9.5	7.6
SCHWA-WACH3	1974	MAR	14.6	N	.94	.69	10.6	69.7	197.4	5.4
SCHWA-WACH3	1979	JUL	27.2	P	.91	.70	10.5	69.2	198.1	5.3
SCHWA-WACH3	1990	MAR	20.9	P	.91	.70	10.5	69.2	198.1	5.3
SCHWA-WACH3	1995	JUL	17.7	N	.91	.70	10.5	69.2	198.1	5.3
SCHWA-WACH3	2006	MAR	11.3	N	.91	.70	10.5	69.2	198.1	5.3
TEMPEL-SWIF	1982	OCT	22.0	N	1.60	.54	13.4	240.0	163.7	6.4
TEMPEL-SWIF	1995	AUG	24.0	N	1.60	.54	13.4	240.0	163.7	6.4
TEMPEL-SWIF	2002	JAN	24.0	N	1.60	.54	13.4	240.0	163.7	6.4
TEMPEL-TUTL	1998	FEB	27.3	N	.98	.91	162.5	234.6	172.5	33.2
TSUCHINSHN1	1978	APR	1.0	N	1.49	.58	10.5	96.2	22.7	6.6
TSUCHINSHN1	1985	JAN	1.0	P	1.49	.58	10.5	96.2	22.7	6.6
TSUCHINSHN1	2004	NOV	29.1	N	1.49	.58	10.5	96.2	22.7	6.6
VAISALA 1	1993	MAY	27.0	N	1.80	.63	11.6	134.5	47.6	10.8
VAISALA 1	2004	MAR	22.0	N	1.80	.63	11.6	134.5	47.6	10.8
VAN HOUTEN	1977	JAN	1.0	N	3.94	.37	6.6	23.0	14.9	15.7
WIRTANEN	1991	SEP	21.1	N	1.08	.65	11.7	81.6	356.2	5.5
WIRTANEN	2008	FEB	10.7	P	1.06	.66	11.7	81.5	356.4	5.5
WOLF 1	1992	AUG	21.0	N	2.42	.41	27.5	203.5	162.2	8.2
WOLF 1	2000	NOV	10.4	N	2.42	.41	27.5	203.5	162.2	8.2

Table 8 COMETS AND MINIMUM DISTANCE LISTED CHRONOLOGICALLY 1974-2010
EARTH-COMET DIST LESS THAN .75 AU

NAME	PERIHELION DATE	INT. CAT.	S.DIS. AU	E.DIS. AU	MINIMUM EARTH DISTANCE D(AU)	TIME	DATE
ENCKE	1974 APR 28	P	.34	.88	.36	46.	1974 JUN 13.
HON-MRK-PAJ	1974 DEC 28	P	.58	.64	.23	39.	1975 FEB 5.
D'ARREST	1976 AUG 12	P	1.16	.15	.15	0.	1976 AUG 12.
GRIGG-SKJEL	1977 APR 10	S	.99	.20	.18	-9.	1977 APR 2.
SCHWA-WACH3	1979 JUL 27	L	.91	.61	.44	35.	1979 AUG 30.
STEPHAN-OTE	1980 DEC 1	P	1.59	.64	.63	10.	1980 DEC 11.
ENCKE	1980 DEC 6	P	.34	1.02	.28	-39.	1980 OCT 28.
TUTTLE	1980 DEC 14	P	1.01	.55	.49	-12.	1980 DEC 2.
SWIFT-GEHRL	1981 NOV 27	S	1.36	.67	.59	46.	1982 JAN 12.
GRIGG-SKJEL	1982 MAY 14	S	.99	.36	.32	16.	1982 MAY 30.
D'ARREST	1982 SEP 14	P	1.29	.73	.70	-30.	1982 AUG 14.
TEMPEL-SWIF	1982 OCT 22	S	1.60	71	.65	26.	1982 NOV 17.
CHURU-GERAS	1982 NOV 1	P	1.28	.55	.52	33.	1982 DEC 3.
TEMPEL 1	1983 JUL 9	S	1.49	.95	.74	-70.	1983 MAY 1.
KOPFF	1983 AUG 13	P	1.57	.96	.75	-64.	1983 JUN 9.
ENCKE	1984 MAR 27	P	.34	.71	.63	9.	1984 APR 5.
AREND-RIGAU	1984 DEC 1	S	1.45	.68	.56	39.	1985 JAN 9.
TSUCHINSHN1	1985 JAN 1	L	1.49	.65	.59	28.	1985 JAN 29.
GIACOBINI-Z	1985 SEP 4	P	1.03	.49	.49	0.	1985 SEP 4.
HALLEY	1986 FEB 9	P	.59	1.55	.62	-74.	1985 NOV 27.
					.42	60.	1986 APR 10.
NEUJMIN 2	1987 APR 2	L	1.27	.64	.58	-55.	1987 FEB 6.
BORRELLY	1987 DEC 18	S	1.36	.50	.48	-12.	1987 DEC 6.
BRORSEN-MET	1988 NOV 7	P	.48	.69	.38	-37.	1988 OCT 1.

Table 8 COMETS AND MINIMUM DISTANCE LISTED CHRONOLOGICALLY 1974-2010
EARTH-COMET DIST LESS THAN .75 AU PAGE 2

NAME	PERIHELION DATE	INT. CAT.	S.DIS. AU	E.DIS. AU	MINIMUM EARTH DISTANCE D(AU)	TIME	DATE
HON-MRK-PAJ	1990 SEP 20	P	.55	.85	.17	-44.	1990 AUG 7.
ENCKE	1990 NOV 3	P	.34	1.19	.73	-32.	1990 OCT 3.
FAYE	1991 NOV 14	P	1.59	.63	.61	-15.	1991 OCT 29.
SCHAUMASSE	1993 MAR 7	S	1.21	.61	.59	-46.	1993 JAN 20.
ENCKE	1994 FEB 21	P	.34	.66	.65	-3.	1994 FEB 18.
TEMPEL 1	1994 JUL 6	S	1.50	.91	.72	-65.	1994 MAY 3.
HARRINGTON2	1994 SEP 2	S	1.59	.67	.64	19.	1994 SEP 21.
BORRELLY	1994 OCT 28	S	1.36	.79	.67	38.	1994 DEC 4.
D'ARREST	1995 JUL 7	P	1.30	.70	.66	33.	1995 AUG 8.
SCHWA-WACH3	1995 JUL 17	L	.91	.46	.30	34.	1995 AUG 20.
JACKSON-NEU	1995 SEP 14	S	1.43	.47	.46	7.	1995 SEP 21.
CHURU-GERAS	1995 DEC 9	P	1.28	.42	.40	-23.	1995 NOV 17.
PERRIN-MRKO	1995 DEC 16	L	1.30	.77	.72	-37.	1995 NOV 8.
HON-MRK-PAJ	1996 JAN 17	P	.55	.87	.27	41.	1996 FEB 27.
KOPFF	1996 JUL 11	P	1.58	.57	.57	-9.	1996 JUL 2.
ENCKE	1997 JUN 11	P	.34	1.12	.42	38.	1997 JUL 19.
TEMPEL-TUTL	1998 FEB 27	L	.98	1.46	.35	-41.	1998 JAN 17.
GIACOBINI-Z	1998 NOV 9	P	1.03	.66	.66	6.	1998 NOV 16.
TEMPEL 2	1999 SEP 6	P	1.48	.81	.64	-55.	1999 JUL 13.
PONS-WINNEC	2002 MAY 25	L	1.26	.50	.47	20.	2002 JUN 14.
DUTOIT-N-DP	2002 AUG 8	L	1.72	.75	.72	-19.	2002 JUL 19.
PERRIN-MRKO	2002 OCT 1	S	1.30	.84	.74	58.	2002 NOV 28.
ENCKE	2004 JAN 17	P	.34	.78	.51	-24.	2003 DEC 24.
TEMPEL 1	2005 JUL 7	S	1.50	.92	.72	-66.	2005 MAY 2.

Table 8 COMETS AND MINIMUM DISTANCE LISTED CHRONOLOGICALLY 1974-2010
EARTH-COMET DIST LESS THAN .75 AU

NAME	PERIHELION DATE	INT. CAT.	S.DIS. AU	E.DIS. AU	MINIMUM EARTH DISTANCE D(AU)	TIME	DATE
HON-MRK-PAJ	2006 SEP 11	P	.55	.93	.30	-43.	2006 JUL 31.
ENCKE	2007 MAY [illegible]	P	.34	.92	.26	45.	2007 JUN 21.
TUTTLE	2008 JAN [illegible]	P	1.01	.38	.08	-20.	2007 DEC 22.
KOPFF	2009 JUN 4	P	1.58	.86	.70	54.	2009 JUL 28.

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