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Comets and How to Observe Them

with 175 Illustrations

Springer

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This book is dedicated to the many people who have helped me along the way. First, to my father and mother, Richard and Winifred Schmude, who first showed me the stars and answered my many science questions; next to the many fine teachers, professors and school administrators who guided me during my childhood and early adulthood; next, to the many librarians at the Hightower Library (Gordon College), the Sterling Evans Library (Texas A&M University) and the Georgia Tech Library who helped me obtain critical information related to this book; and finally, to the American taxpayers who made it possible to send spacecraft to several of the comets described in this book.

Author's Note

I became interested in astronomy initially when I saw what appeared to be a countless number of stars from my parent's home in Cabin John, Maryland. I was no older than six when I had this life-changing view of the night sky. I purchased my first telescope at age 15 and shared it with siblings and a neighbor girl – Kathy. This was my first experience with public outreach.

My first view of a comet was on March 21, 1986. My brothers James, Fred, and I got up on a cold morning to view Halley's Comet. Since then, I have viewed several comets. What I have come to realize in my studies of comets is that each one is unique.

This book is broken down into two major parts. The first one (Chapters 1 and 2) summarizes our current understanding of comets. In Chapter 2, I have chosen to describe in detail our current knowledge of four comets – 9P/Tempel 1, 1P/Halley, 19P/Borrelly, and 81P/Wild 2. The second part describes observational projects that one may carry out with the unaided eye and binoculars (Chapter 3), small telescopes (Chapter 4) and large telescopes (Chapter 5). Finally, an appendix, a bibliography and an index are included.

The three organizations which are engaged in serious comet studies and with which I am most familiar are the Association of Lunar and Planetary Observers (ALPO), the British Astronomical Association (BAA), and the organization that publishes the *International Comet Quarterly*.

Various websites are quoted in this book. All of them existed in July 2009; some however, may change or be discontinued by the time that this book is read. Changes in websites or addresses are bound to happen. What I have often seen, though, is that a discontinued website is replaced by something even better.

About the Author

Dr. Richard Willis Schmude, Jr. was born in Washington, DC, and attended public schools in Cabin John, Maryland; Los Angeles, California; and Houston, Texas. He started his college career at North Harris County College and graduated from Texas A&M University with a Bachelor of Arts degree in Chemistry. Later, he obtained a Master of Science degree in Chemistry, a Bachelor of Arts degree in Physics, and a Ph.D. in Physical Chemistry, all from Texas A&M University. He worked at NALCO Chemical Company as a graduate co-op student and at Los Alamos National Laboratory as a graduate research assistant.

Since 1994, Dr. Schmude has taught astronomy, chemistry, and other science classes at Gordon College in Barnesville, Georgia. He is a tenured Professor at this college and continues to teach his students (and others) in these areas. He has published over 100 scientific papers in many different journals, and has given over 500 talks, telescope viewing sessions, and workshops to over 20,000 people.

Contents

Chapter 1

Comets: An Overview

Introduction

When I think of a comet, I imagine a bright object with a long tail. Many comets fit this description; however, most are very faint and lack visible tails. In the dictionary, a comet is defined as a celestial body moving about the Sun and having a solid portion which is surrounded by a misty envelope which may or may not have a tail. In many cases, the misty envelope may be faint, and, hence, a comet could resemble an asteroid. There are a large number of known comets, perhaps the most famous one being "Halley's Comet" which orbits our Sun approximately every 76 years.

Most comets have four visible parts. See Fig. 1.1. The central condensation is the bright central part of the coma. The coma is a gaseous envelope that surrounds the central condensation. It can have either a circular, elliptical or parabolic shape. The dust tail lies beyond the coma and is usually the brightest portion of the tail. It is made up of dust. The gas tail is made up of ions, gas atoms and gas molecules. It often has a bluish color.

This chapter describes the characteristics of a comet. Its sections are "Naming Comets", "Comet Orbits", "Comet Orbits and Kepler's Second and Third Laws of Planetary Motion", "Classification of Comets", "Sources and Movement of Comets", "Comet Brightness and Some Statistics", "Parts of a Comet", "Brightness Changes of Comets over Time" and "Comet Impacts in the Near Past".

Naming Comets

In early 1995, a new system of naming comets was established. If the comet is believed to be newly discovered, its designation would be constructed from the steps in Fig. 1.2. Table 1.1 lists the time intervals and the corresponding letter sequences mentioned in the second box in Fig. 1.2. The last name of the person(s) who discovered the comet may be added to this designation, limited, however, to three last names. For example, Comet Hale-Bopp (C/1995 O1) is named after Alan

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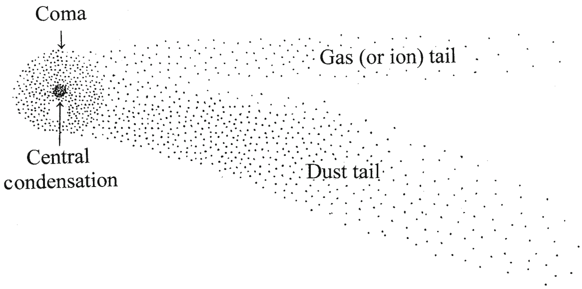

Fig. 1.1. Visible parts of a comet (credit: Richard W. Schmude Jr.).

C/ is added to the year of discovery.

↓

An upper-case letter is assigned based on the half-month of discovery. The letter A is assigned to discovery dates between Jan. 1 and 15, B to discovery dates between Jan. 16 and 31 and so forth. The letter I is not used. See also Table 1.1

↓

A number is placed after the letter indicating the order of discovery in the half-month. The upper-case letter and number follow the C/year designation.

↓

If the comet has an orbital period of just a few years or a few decades, the C/designation would be changed to a P/designation.

↓

If the comet appears after one orbital period, the new designation would be a number followed by P/. This number is one more than the number of numbered periodic comets.

↓

The names of up to three people who discovered the P/ comet may be added after the / in the designation. The names are added to the designation for C/ comets. The full comet name includes the designation and the name(s) of the discoverer(s).

Fig. 1.2. Steps used in naming a comet. See also Table 1.1 (credit: Richard W. Schmude Jr.).

Hale and Thomas Bopp. The full name is Hale-Bopp C/1995 O1, and its designation is C/1995 O1. If two people who have the same last name discover a comet, such as Gene and Carolyn Shoemaker, it would be given the last name of both individuals (Shoemaker). If several people are involved with a discovery at an observatory, the comet may be named after the observatory instead of the indi-

Table 1.1. Time intervals and letter designations which are used in naming a comet

Time interval	Letter	Time interval	Letter	Time interval	Letter
Jan. 1–15	A	May 1–15	J	Sept. 1–15	R
Jan. 16–31	B	May 16–31	K	Sept. 16–30	S
Feb. 1–15	C	June 1–15	L	Oct. 1–15	T
Feb. 16–28 (or 29)	D	June 16–30	M	Oct. 16–31	U
Mar. 1–15	E	July 1–15	N	Nov. 1–15	V
Mar. 16–31	F	July 16–31	O	Nov. 16–30	W
Apr. 1–15	G	Aug. 1–15	P	Dec. 1–15	X
Apr. 16–30	H	Aug. 16–31	Q	Dec. 16–31	Y

viduals. An example of this is Comet Siding Spring (C/2007 K3). Many comets are named after the all-sky survey which resulted in their discoveries. An example would be Comet LINEAR (C/2008 H1). A few of the all sky surveys include the Lincoln Near Earth Asteroid Research (LINEAR), the Near-Earth Asteroid Tracking Program (NEAT), the Catalina Sky Survey (CSS), the Lulin Sky Survey (Lulin) and the Lowell Observatory Near-Earth Object-Search (LONEOS).

A comet is named after its discoverer (or discoverers) provided that it is not a returning comet or it was not discovered previously as another object, such as an asteroid. In rare cases, a comet is named also after the person who determines its orbit. The English astronomer, Edmund Halley, for example, determined that the comets which appeared in 1456, 1531 and 1607 had orbits which were similar to the comet which appeared in 1682, and he predicted that one 1682 comet would return about 1758. (See *Comet Science* ©2000 by Jacques Crovisier and Thérèse Encrenaz.) The comet returned in 1759 and, hence, it bears his name – Comet (1P/Halley).

If the same person discovers more than one comet a number would follow the name. For example, E. W. L. Tempel discovered two different Short-period comets, one in 1867 and another in 1873. These comets are named Tempel 1 and Tempel 2, respectively. This rule applies also to comets with the names of two or three co-discoverers. For example, Comet Shoemaker-Levy 9 is the ninth comet discovered by the Shoemaker-Levy team.

Most of the Sungrazing comets are discovered by individuals who analyze images made by the Solar and Heliospheric Observatory (or SOHO) probe. These comets are designated in Fig. 1.2 and are named after the SOHO probe instead of the individual who made the particular discovery. A few Sungrazing comets are also named after the Solar Maximum Mission (or SMM) spacecraft, the SOLWIND spacecraft and the Solar Terrestrial Relations Observatory (or STEREO) spacecraft.

The letter C in Fig. 1.2 may be replaced by a P, D or X depending on the nature of the comet. An explanation follows.

If a comet is found to have a short orbital period, it would be given the P/ designation until it is recovered in a second apparition. At this point, the P/Year designation would be replaced with a number followed immediately by an upper case P; and a slash followed by the name of the person who discovered it. The number here is one more than the number of known periodic comets that have reappeared. For example, Comet Hug-Bell (P/1999 X1) was given the full name 178P/Hug-Bell after it reappeared in 2007. Since 177 periodic comets had been assigned numbers before Hug-Bell reappeared, this comet was given number 178.

If a comet is destroyed, or if it fails to appear after several apparitions, it would be given the designation of D/ followed by the year of its discovery. For example, Comet Shoemaker-Levy 9 has been assigned D/1993 F2 since it was discovered in the second half of March in 1993 and was destroyed when it crashed into Jupiter in 1994.

Comets that are believed to be real but lack sufficient position measurements for an orbital determination are given the designation of X/ followed by the year of discovery and the appropriate letter and number code. For example, Comet X/1896 S1 was first seen on Sept. 21, 1896, by L. Swift at Lowe Observatory in California. Apparently he was the only one to see the comet and was unable to determine enough positions for an orbital determination. Kronk lists 18 comets with the X/ designation that people had seen in the nineteenth century.

An unusual situation occurs when a comet's nucleus splits. In this case, each fragment is given the comet designation followed by A, B, C, etc. For example, the nucleus of comet LINEAR C/2003 S4 split into two parts. Astronomers named the two parts LINEAR C/2003 S4-A and LINEAR C/2003 S4-B. Each part is treated as a separate comet.

Astronomers have discovered many objects which were believed to be minor planets but were later determined to be comets. These objects retain their minor planet designation but are given either a C/ or P/ prefix. For example, astronomers imaged a magnitude 19.3 object on Feb. 18, 2004, and reported it as a minor planet. This object was given the minor planet designation 2004 DZ_{61}. A few weeks later, a different group of astronomers at Mauna Kea in Hawaii imaged this object but found that it had a small coma with a faint tail. This object was reclassified as a comet and was given the designation C/2004 DZ_{61}.

The name of the discoverer of the comet will be used whenever possible for the remainder of this book. For periodic comets the P/number designation is used. For C/ comets, the designation is placed in parentheses. Older designations which include a year and a roman numeral or a year and a lower-case letter will not be used.

Comet Orbits

Like the Earth, comets in our Solar System move under the influence of the Sun's gravity. Comets follow one of four paths, namely, circular, elliptical, parabolic or hyperbolic; and a comet's path is determined by six quantities which are called orbital elements. In this section, comet paths, orbital elements and how astronomers refine a comet's orbit are discussed.

Comets under the gravitational influence of a single large object like our Sun can move in one of four paths. Each of these is illustrated in Fig. 1.3. Comets which move in a circular orbit maintain a constant Sun distance, the Sun being located in the center of such orbit. Comets which move in an elliptical orbit have a varying Sun distance. Ellipses can have different shapes, ranging from nearly circular to very stretched out. See Fig. 1.4. The eccentricity defines how the ellipse is stretched out. If the eccentricity is low the ellipse would have an almost circular shape,

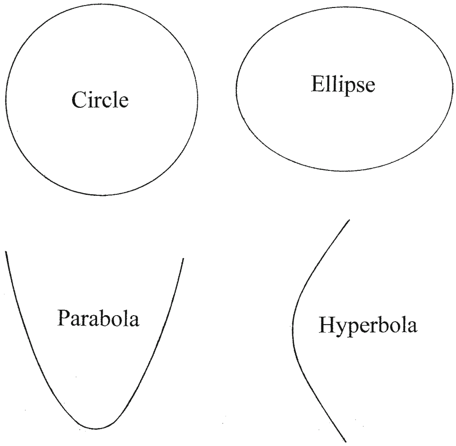

Fig. 1.3. A comet's path can be any one of the four modes shown here (credit: Richard W. Schmude Jr.).

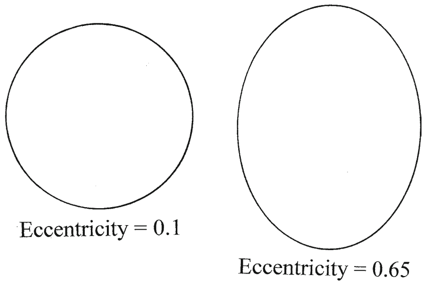

Fig. 1.4. The ellipse on the *left* has an eccentricity of 0.1 and is nearly circular. The one on the *right* has an eccentricity of 0.65 and is much more squashed (credit: Richard W. Schmude Jr.).

whereas if the eccentricity is high, it would be stretched out. The eccentricity is defined as the distance between the two foci points (F1 and F2) divided by the length of the major axis (line segment A B) in the ellipse. See Fig. 1.5. Ellipses can have an eccentricity of just above 0.000 to just below 1.000. Comets which move in circular or elliptical paths will orbit our Sun. Comets which move in a parabolic or hyperbolic path may never return to the Sun. A parabolic orbit has an eccentricity of exactly 1.0. The eccentricity of a hyperbolic orbit is greater than 1.0.

As for orbital elements, which are discussed in the subsection below, one will need to note that all orbital elements have some uncertainty. One source of uncertainty is in the position measurements. Each measurement of a comet's position has an uncertainty in time, right ascension and declination. A second source of orbital uncertainty is due to gravity. Gravitational forces exerted by other Solar System bodies will change a comet's orbit and, hence, its orbital elements. A third source of uncertainty results from several types of non-gravitational forces. These non-gravitational forces are described later in this chapter. As a result of these

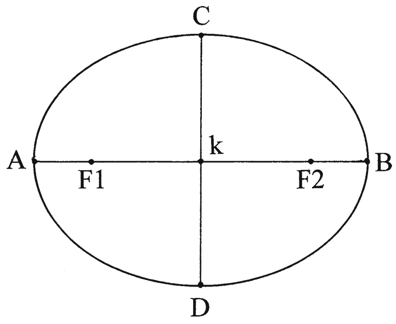

Fig. 1.5. The major axis runs from points A to B, and the semi major axis has half the length (A – k or B – k) of the major axis. The two foci points are at F1 and F2. The eccentricity is the distance between the two foci points divided by the length of the major axis. In this example, the eccentricity equals 0.66 (credit: Richard W. Schmude Jr.).

uncertainties, a comet may have a computed orbital eccentricity just over 1.0 but, in reality, it may be just below 1.0.

The elliptical and hyperbolic paths have a range of eccentricities, whereas circular and parabolic paths have eccentricities of exactly zero and one, respectively. In nature, comets will follow paths having eccentricities which will be between either zero and one or above one; but never *exactly* zero or one. Because of this, it is believed that comets should be broken down into three groups which are Short-period, Long-period and No future predictions. Comets in the Short-period group have orbital periods of less than 200 years and will have orbital eccentricities below 1.0. Comets in the Long-period group include both periodic comets with orbital periods over 200 years and comets which are not returning to the inner Solar System. Comets in this group have orbital eccentricities near 1.0 or just over this amount. They will follow either elliptical orbits which are very stretched out or hyperbolic orbits. Comets falling into the third category (No future predictions) are either lost or have been destroyed and are given the designation D/. Table 1.2 gives a breakdown of the percentage of each type of comet.

Can a comet following one path be pushed into another one? Yes! The most common situation occurs when a comet enters our Solar System following an elliptical orbit and makes a close approach to one of the planets. As a result, its path would change to a hyperbolic one, and the comet would leave our Solar System.

Of the almost 1,000 comets listed with a C/ designation in the *Catalogue of Cometary Orbits 2008* (17th edition) by Brian G. Marsden and Gareth V. Williams, 23% of them have an eccentricity above 1.000000 and 77% of them have an eccentricity below 1.000000.

Orbital Elements

A comet's path is determined mathematically by six quantities which are called orbital elements. These quantities are used in determining the different groups, families and sub-groups of comets. They also yield information on the source of comets. A description of these quantities follows.

Table 1.2. Percentages of comets in different groups, families and sub-groups as of mid-2008, with all of the percentages expressed in terms of the total number of C/, P/ and D/ comets. The writer computed the percentages from data in *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams

Short-period group (C/ and P/ comets)	13.8%
Encke Family	0.6%
Jupiter Family	11.1%
Chiron Family	0.3%
Short-period nearly isotropic NI Family	1.6%
Kracht 2 Family	0.1%
Long-period group (C/ and P/ comets)	84.7%
Sungrazer Family	51.9%
Kreutz sub-group	44.6%
Meyer sub-group	3.1%
Marsden sub-group	1.1%
Kracht 1 sub-group	1.1%
Kracht 3 sub-group	0.1%
Anon 1 sub-group	0.1%
Anon 2 sub-group	0.1%
Unclassified (Sungrazer)	1.7%
Long-period nearly isotropic NI Family	32.8%
No future predictions (D/ comets)	1.5%

The first quantity is the date and time of perihelion passage. Perihelion is the point on the path where the comet is closest to the Sun. If a comet follows an elliptical orbit, this date and time would be specified for each perihelion passage. The symbol for the date and time of perihelion passage is T.

The comet-Sun distance at perihelion is the second quantity needed for determination of a comet's path. This distance is given in astronomical units with the symbol of q. This quantity is the distance between the Sun and point q in Fig. 1.6.

A third quantity is the angle between the plane containing the comet's path and the plane containing the Earth's orbit. This angle is called the orbital inclination, and it has the symbol of i. It can range from 0° up to 180°. An inclination of 180° is the same as 0° except that the comet moves in the opposite direction in which the Earth moves around the Sun. If a comet moves in the same direction as the Earth and remains in Earth's orbital plane, its orbital inclination would equal 0°. The orbital inclination is illustrated in Fig. 1.6.

A fourth quantity is the comet's orbital eccentricity. As mentioned earlier, this determines the shape of the path which the comet follows. The symbol for its orbital eccentricity is e.

The fifth and sixth quantities needed for determination of a comet's path are the longitude of the ascending node (symbol = Ω) and the argument of perihelion (symbol = ω).

The two points where the comet's path intersects the Earth's orbital plane are called nodes. The ascending node is the point where the comet moves from south to north of the Earth's orbital plane. The descending node is the point where the comet moves from north to south of Earth's orbital plane. The longitude of the ascending node is the angle between a line connecting the Sun and equinox point

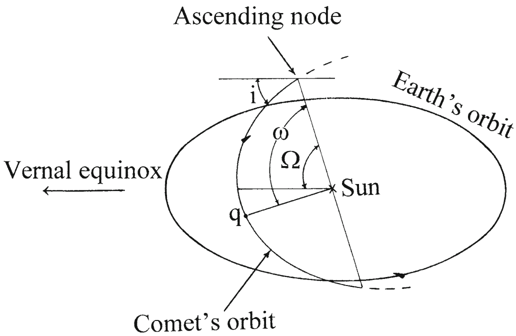

Fig. 1.6. Orbital elements of a comet. The orbital inclination (i), perihelion point (q), longitude of the ascending node (Ω), and argument of perihelion (ω) are illustrated in the drawing. Note that the perihelion distance is the distance between the Sun and point q (credit: Richard W. Schmude Jr.).

Table 1.3. Orbital elements and other characteristics of Comet Shoemaker-Levy 9 (D/1993 F2) listed in various International Astronomical Union Circulars

IAU circular number	5744	5800	5892 and 5893	5906	6017
Date of IAU circular	April 3, 1993	May 22, 1993	November 22, 1993	December 14, 1993	July 9, 1994
Orbital eccentricity (e)	0.07169	0.065832	0.206613	0.207491	–
Orbital inclination (i) (degrees)	2.206	1.3498	5.7864	5.8254	–
Orbital period (years)	11.45	11.728	17.670	17.685	–
Predicted date of closest approach to Jupiter in 1992	A distinct possibility	July 8.8	July 8.0	July 7.8	–
Predicted date of first impact (1994)	No mention of an impact	July 25.4	July 18.7	July 17.6	July 16.826
Predicted date of last impact	No mention of an impact	July 25.4	July 23.2	July 22.3	July 22.330

and a second line connecting the Sun and the ascending node. The equinox point is the location of the Sun in the sky at the first moment of spring in the Earth's northern hemisphere. The argument of perihelion- ω is the angle between the line connecting the Sun and the perihelion point and a second line connecting the ascending and descending nodes. See Fig. 1.6.

Determination and Refinements of a Comet's Orbital Elements

Once a comet is discovered, one of the first things that astronomers do is to measure its position. Repeated position measurements are used in computing its path and future positions. Future positions will serve as an aid for making more position measurements and a refinement of the comet's path. The accuracy of the path improves as the number of position measurements increases and as the time interval of the position measurements increases. For example, Table 1.3 shows the computed orbital eccentricity, the orbital period and other predictions of Comet Shoemaker-Levy 9 (D/1993 F2). This table illustrates that as astronomers made more position measurements of this comet, they learned that it made a close passage to Jupiter in early July of 1992. With more refinement, they determined that it would crash into Jupiter and were able eventually to predict the time of the crash to an accuracy of a few minutes.

Comet Orbits and Kepler's Second and Third Laws of Planetary Motion

If a comet moves in an elliptical orbit around the Sun without pull from other bodies, its orbit would not change. It would not grow larger or smaller. This type of motion is called regular motion and its orbit is referred to as a Kepler-type orbit; and, in this context, it would prove the correctness of Kepler's Second and Third Laws of Planetary Motion. However, all comets which enter or are in our Solar System experience gravitational tugs by the planets, which are called perturbations. As a result of perturbations, Kepler's Second and Third laws are compromised, but, in many cases, they may be used as a *good approximation* of a comet's movement.

Figure 1.7 shows the orbit of Comet 1P/Halley. Kepler's Second Law states that a line connecting the Sun to an object that orbits the Sun sweeps out equal areas in equal intervals of time. If for example, the area swept out by this line in going from point A to point B equals the area swept out in going from point D to point C then the time it takes for the comet to go from point A to point B will equal the time it takes in going from point D to point C. Obviously the distance between point A and point B is much greater than the distance between point D and point C. Therefore this shows that the comet moves much faster when it is close to the Sun. Figure 1.8 shows approximate velocities of this comet at different points along its elliptical orbit. It moves fastest when it is at perihelion and moves slowest when it is at aphelion – its farthest distance from the Sun. One consequence of Kepler's Second Law is that a comet moves fastest when it is closest to the Sun (due to stronger gravitational pull).

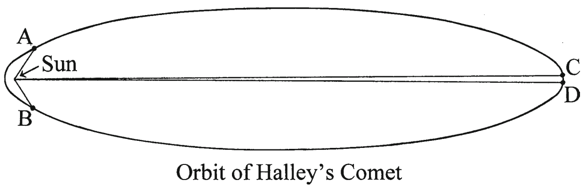

Fig. 1.7. A drawing illustrating Kepler's Second Law of Planetary Motion. It takes Halley's Comet 1 year to travel from points A to B and from points C to D. Since this comet is close to the Sun at points A and B, it moves much faster than when it is at points C and D. This is due to Kepler's Second Law which states that a line connecting the Sun to an orbiting planet (or comet) sweeps out equal areas in equal time (credit: Richard W. Schmude Jr.).

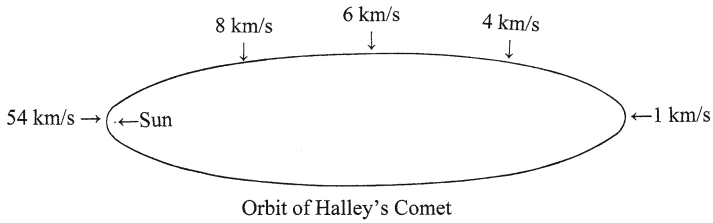

Fig. 1.8. A drawing showing the approximate orbital velocities of Comet 1P/Halley at different locations in its orbit (credit: Richard W. Schmude Jr.).

Comets in an elliptical orbit obey Kepler's Third Law of Planetary Motion. This law states that for objects orbiting our Sun, there is a relationship between the orbital period and the average distance from the Sun. Essentially, the farther an object is from the Sun, the longer that it will take for that object to orbit the Sun. Kepler's Third Law in equation form is:

$$p^2/r^3 = 1\ \text{year}^2/\text{au}^3 \quad \text{(for objects orbiting our Sun)} \qquad (1.1)$$

or

$$r = \left[p^2 \times \text{au}^3/\text{year}^2\right]^{1/3} \qquad (1.2)$$

In these equations, p is the orbital period, r is the average comet-Sun distance (or the semimajor axis of the comet's orbit) and au is an abbreviation for astronomical unit. By knowing the orbital period, one can compute the comet's average distance from the Sun.

Classification of Comets

Table 1.2 shows the percentage breakdown for different families and sub-groups of comets. Comets with an X/ in their designation are not included in Table 1.2. (In all cases, the orbital statistics quoted in this Section are based on comets known as of mid-2008. Orbital parameters are from *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams.) Long-period comets make up 84.7% of all known comets. This group contains two large families of comets – the sungrazer family, with 51.9% of all known comets, and the long-period nearly isotropic family with 32.8% of all known comets. The short-period group contains 13.8% of all known comets, with the Jupiter family making up most of this group.

Comets in a family have similar orbits and are controlled by similar gravitational forces. In many cases, comets in a family also have a similar source. The mathematics used in dividing comets into different families is complex.

Many astronomers rely on the Tisserand Parameter (T) to divide comets into families. According to *Encyclopedia of the Solar System, 2nd edition* ©2007 by Lucy-Ann McFadden et al., the Tisserand Parameter, T, is defined as:

$$T = (j/r) + 2 \times \left[(1 - e^2) \times r / j\right]^{1/2} \times \cos(i) \quad (1.3)$$

In this equation j = 5.20280 au and is Jupiter's average distance from the Sun; r is the comet's average distance from the Sun; e is the orbital eccentricity of the comet's path; i is the orbital inclination of the plane containing the comet's path in degrees; and cos is the cosine function.

The Tisserand Parameter (T) is a useful tool in establishing comet families in the short-period group. Figure 1.9 contains a flowchart illustrating different comet families in this group. If T is less than 2.0, the comet would belong to the nearly isotropic family. If T is between 2.0 and 3.0, the comet would be in the Jupiter family. If T exceeds 3.0, it would be in either the Encke or Chiron family depending on the size of its orbit. Table 1.4 lists several comets, certain orbital elements, Tisserand Parameter values and the families to whom they belong. Figures 1.10–1.12 illustrate the orbits of Jupiter along with the orbits of Comets 2P/Encke, 17P/Holmes and 95P/Chiron, respectively. Comet 2P/Encke lies always inside of Jupiter's orbit with the Sun, and it never gets close to Jupiter. Comet 95P/Chiron lies always outside of Jupiter's orbit, and, hence, it does not get close to Jupiter. Comet 17P/Holmes, on the other hand, may get close to Jupiter, and, hence, Jupiter's gravity would affect its orbit. In the next section, short-period comets and the families in this group are described.

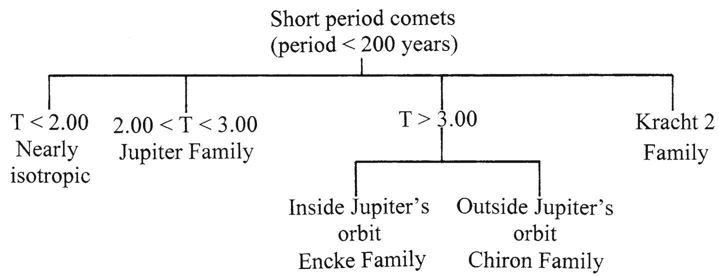

Fig. 1.9. A flowchart illustrating the different families of comets within the Short-period group of comets (credit: Richard W. Schmude Jr.).

Table 1.4. Orbital elements, the Tisserand parameter (T) and assigned family for a few comets. The general orbital elements of a comet are illustrated in Fig. 1.6; all data in this table are from *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams

Comet	Perihelion distance – q (au)	Orbital eccentricity – e	Orbital inclination – i (degrees)	Tisserand parameter – T	Family
1P/Halley	0.5871	0.9673	162.2	–0.607	Short-period nearly isotropic
2P/Encke	0.3393	0.8470	11.75	3.03	Encke
9P/Tempel 1	1.506	0.5175	10.53	2.97	Jupiter
17P/Holmes	2.053	0.4324	19.11	2.86	Jupiter
95P/Chiron	8.454	0.3831	6.93	3.36	Chiron

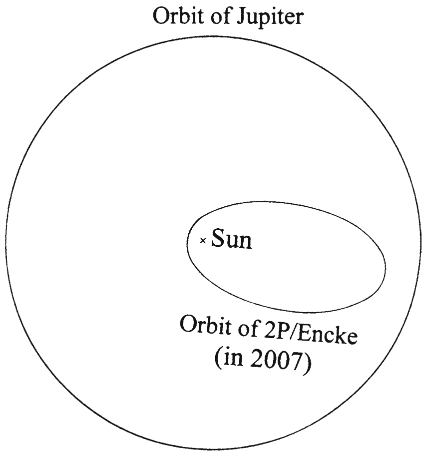

Fig. 1.10. A comparison of the orbits of Comet 2P/Encke in 2007 and Jupiter. Note that this comet never gets as far from the Sun as does Jupiter. As a result, it never gets close to Jupiter (credit: Richard W. Schmude Jr.).

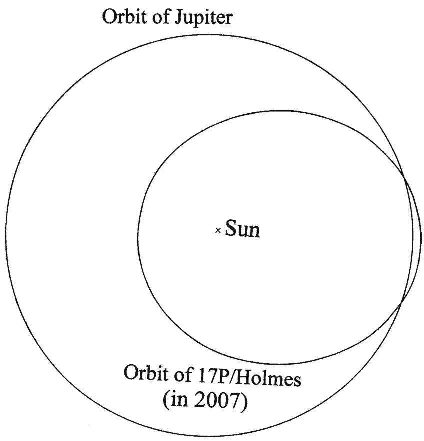

Fig. 1.11. A two-dimensional comparison of the orbits of Comet 17P/Holmes in 2007 and Jupiter. Note that the orbits of the two bodies overlap slightly. This means that they may come closer to one another in time (credit: Richard W. Schmude Jr.).

Short-Period Group

The short-period group contains the Encke, Chiron, Jupiter, Short-period nearly isotropic and Kracht 2 families. The orbital characteristics of these families are discussed below.

Comets in the Encke family have orbits inside that of Jupiter. Their movements, however, are not controlled by Jupiter's gravity. Another of their characteristics is that they have fairly low inclinations. All of them have orbital inclinations below 12°. They, however, may have a wide range of orbital eccentricities, as illustrated

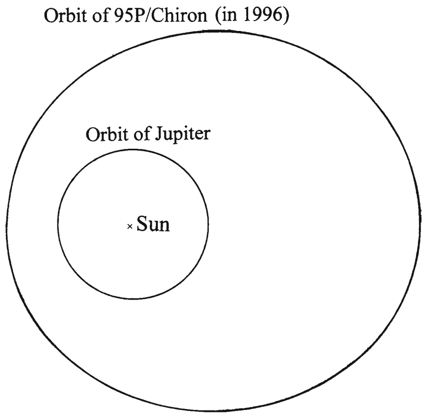

Fig. 1.12. A comparison of the orbits of Comet 95P/Chiron in 1996 and Jupiter. Note that the comet does not get close to Jupiter (credit: Richard W. Schmude Jr.).

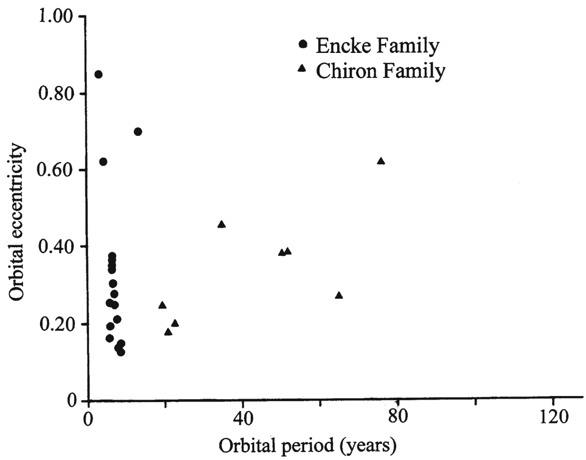

Fig. 1.13. A graph of the orbital eccentricity versus the orbital period (in years) for comets in the Encke and Chiron Families. Data are from *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams (credit: Richard W. Schmude Jr.).

in Fig. 1.13. This figure shows a graph of the orbital eccentricity versus the orbital period of comets in the Encke and Chiron families. Therefore, comets in the Encke family follow orbits that range from being nearly circular to those that are stretched out.

Comets in the Chiron family follow paths which lie beyond Jupiter's orbit. Like the Encke family, these comets are not controlled by Jupiter's gravity. At least one comet in this family, 95P/Chiron, crosses Saturn's orbit and, hence, it may make a close pass to that planet. Comets in the Chiron family have low orbital inclinations. All of them have inclinations below 24°, and 63% of them have inclinations below 12°. Comets in this family have a wide range of eccentricities like those in the Encke Family. The orbital periods range from 20 to almost 80 years. See Fig. 1.13.

Most of the Short-period comets fall in the Jupiter family. This means that Jupiter's gravitational field affects strongly their movement. Jupiter family comets can pass close to Jupiter. Jupiter's orbital inclination is 1.3°, and, hence, most comets in this family have paths that are not in Jupiter's orbital plane. In spite of this, some of these comets cross Jupiter's path. Comet Shoemaker-Levy 9 (D/1993 F2) had an orbital inclination of 6.0° but in July 1994, it not only crossed Jupiter's path but collided with it. Figure 1.14 shows the percentages of Jupiter family comets with different orbital inclinations. Most of these comets have an orbital inclination below 24° which is similar to the Encke and Chiron families. Figure 1.15 shows the orbital period versus orbital eccentricity for Jupiter family comets. Jupiter family comets have a wide range of orbital eccentricities. Those with periods longer than about 25 years tend to have high eccentricities. High eccentricities are the only way that these comets can get close to Jupiter and, hence, come under its gravitational influence.

Comets in the short-period, nearly isotropic (NI) family have a different distribution of orbital inclinations than those in the Encke, Chiron and Jupiter families. Figure 1.16 shows the percentage of Short-period NI comets with different orbital inclinations. The figure shows that there is a fairly even distribution of orbital inclinations which is in contrast to comets in the Encke, Chiron and Jupiter families. The difference in inclination suggests that there is a different source for the Short-period NI comets compared to the other three families of comets discussed above. Astronomers believe that the Oort Cloud is the main source of short-period NI comets because of the almost even distribution of orbital inclinations. The Oort Cloud, named after Dutch astronomer Jan Hendrix Oort, is a spherical shell extending from 3,000 au (or 0.05 light years) to about 100,000 au (or about 1.6 light years) from the Sun. There may be as many as 10^{12} icy objects in this cloud that are big enough to become comets. Because of the abundance of low orbital inclinations for the Encke, Chiron and Jupiter families, astronomers believe that their main source of origin is the region just beyond Neptune.

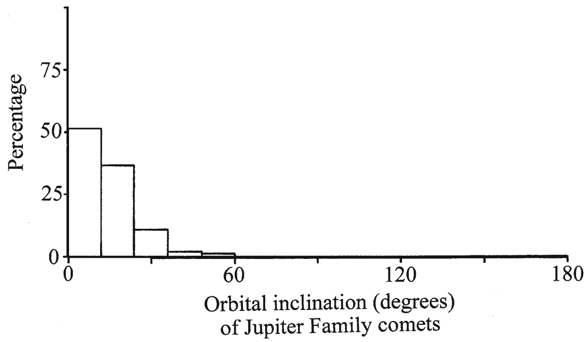

Fig. 1.14. A graph of the percentage of comets in the Jupiter Family having different orbital inclinations. Data are from *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams (credit: Richard W. Schmude Jr.).

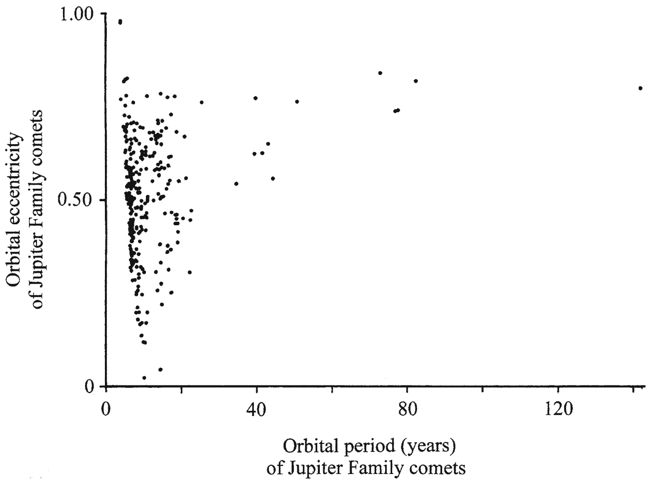

Fig. 1.15. A graph of the orbital eccentricity versus the orbital period for comets in the Jupiter family. Note that comets having an orbital period of less than about 15 years have a wide range of orbital eccentricities whereas those with an orbital period above 30 years have orbital eccentricities above 0.5. Data are from *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams (credit: Richard W. Schmude Jr.).

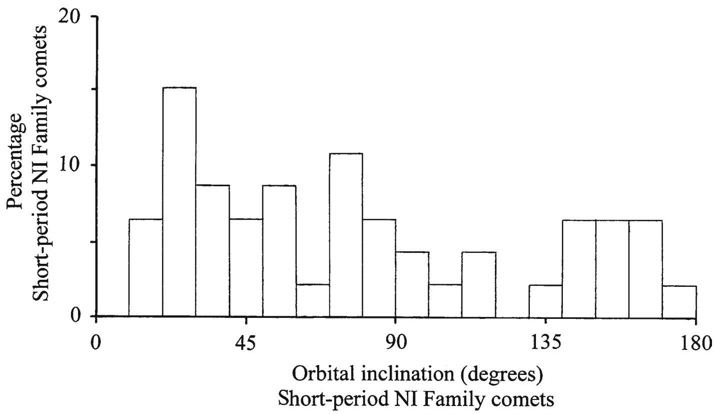

Fig. 1.16. This graph shows the percentage of comets in the Short-period nearly isotropic (NI) family with different orbital inclinations. Note the fairly even distribution of orbital inclinations. Data are from *Catalogue of Cometary Orbits 2008, 17th edition* ©2008 by Brian G. Marsden and Gareth V. Williams (credit: Richard W. Schmude Jr.).

Figure 1.17 shows a graph of the orbital eccentricity plotted against the orbital period of Short-period NI comets. (Comets 153P [period = 364 years, eccentricity = 0.990062] and C/1937 D1 [period = 187 years, eccentricity = 0.981] are not included in Fig. 1.17.) In all cases, these comets have orbital eccentricity values greater than 0.60. This means that comets in this family follow stretched out orbits. They will get close to the Sun for a short period of time and will remain far from the Sun for the remainder of the time.