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THE HISTORY OF COMET HALLEY

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ABSTRACT

A summary is given of the dynamical history of Comet Halley (complete with ephemerides for each known apparition) and also of the physical observations made during the most recent apparitions.

I. *The Dynamical History of Comet Halley.* I.1. *The Prediction of Future Perihelion Passage Times.* Since 240 B.C., Chinese observers have documented a nearly unbroken record of scientifically useful observations of Comet Halley (Ho Ping-Yü, 1962; Ho Ping-Yü and Ang Tian-Se, 1970). After the probable 240 B.C. apparition, only the 164 B.C. return went unrecorded by the Chinese, and with the exception of occasional Korean and Japanese sightings, useful Comet Halley observations made outside China were virtually non-existent for over a millennium thereafter. Beginning with the cometary observations of the Florentine physician and astronomer, Paolo Toscanelli (1397–1482), quantitative and accurate cometary positions gradually came to be made throughout the West (Celoria, 1893). However, the necessary theory for representing a comet's motion was not available until the publication of Isaac Newton's *Principia* in 1687. Newton (1687) outlined a semi-analytic orbit-determination theory and used the comet of 1680 as an example. While Newton never applied the method to another comet, Edmond Halley, carrying out what he termed "a prodigious deal of calculation," used it to determine the parabolic orbits for two dozen well observed comets (Halley, 1705). Struck by the similarity in the orbital elements for the comets observed in 1531, 1607, and 1682, Halley suggested that these three apparitions were due to the same comet, and that it might be expected again in 1758. Halley's subsequent calculations indicated that a close Jupiter approach in 1681 would cause an increase in the length of the next period. Halley then revised his earlier prediction and suggested in a publication appearing after his death (Halley, 1749) that the comet that was to bear his name would return again in late 1758 or early 1759.

To refine Halley's prediction, Clairaut (1758) used a modified version of his analytic lunar theory to compute the perturbations on the comet's orbital period caused by Jupiter and Saturn over the interval 1531–1759. Noting that calculations over the intervals 1531–1607 and 1607–1682 predicted the 1682 perihelion passage time to within one month, Clairaut stated that his mid-April 1759 prediction should be good to a similar accuracy. The actual time of perihelion passage in 1759 was March 13.1 (unless otherwise stated, all times are given in U.T.). Beginning with Clairaut's work in 1758, all investigations to 1910 of the perturbed motion of Comet Halley were based upon the variation-of-elements technique (Lagrange, 1783). The various studies differed only in how many perturbing planets were included, how many orbital elements were allowed to vary, and how many times per revolution the reference ellipse was rectified by adding the perturbations in elements. Until after the 1909–1911 apparition, no attempt was made to link the observations of two or more apparitions into one orbital solution.

In anticipating the 1835 return, Damoiseau (1820) computed the perturbative effects of Jupiter, Saturn, and Uranus on Comet Halley over the interval 1682–1835. Since the actual time of perihelion passage in 1835 was November 16.4, Damoiseau's initial prediction of November 17.15 was remarkable. However, Damoiseau (1829) later added the perturbations due to the Earth and revised his prediction to November 4.81. De Pontécoulant considered the perturbative effects of Jupiter, Saturn, and Uranus over the interval 1682–1835 as well as the Earth's perturbative effects near the 1759 perihelion passage. His predictions for the 1835 perihelion passage time were, successively, November 7.5, November 13.1, November 10.8 and finally November 12.9 (de Pontécoulant, 1830, 1834, 1835). The most exhaustive work leading up to the 1835 return was undertaken by O.A. Rosenberger. After a complete reduction of available observations, Rosenberger recomputed an orbit for the 1759 and 1682 apparitions (Rosenberger 1830a, 1830b). He (1834, 1835) computed the effect on all the orbital elements from the perturbations of the seven known planets over the 1682–1835 interval. Assuming the comet's motion was unaffected by a resisting medium, he predicted that the 1835 perihelion passage time was November 12.0. Lehmann (1835) also investigated the motion of comet Halley over the 1607–1835 interval, taking into account the perturbative effects of Jupiter, Saturn, and Uranus. However, his perihelion passage prediction was late by more than 10 days.

In an effort to anticipate the next apparition of Comet Halley, de Pontécoulant (1864) took into account the perturbative effects of Jupiter, Saturn, and Uranus before predicting May 24.36, 1910, as the next time of perihelion passage. The actual time turned out to be April 20.18. Ivanov (1909) began his study with a set of initial conditions based upon the

1835–1836 observations and integrated the comet's motion forward to December 1909 taking into account the planetary perturbations from Mercury to Neptune where appropriate. He predicted a perihelion passage time of 1910 April 22.91. Cowell and Crommelin began their work with preliminary calculations to see if de Pontécoulant's prediction was approximately correct (Cowell and Crommelin, 1907a, 1907b, 1907c, 1908c). Their computations used the variation-of-elements technique, included perturbations by all the planets from Venus to Neptune (except Mars), and predicted a return to perihelion on April 8.5. Cowell and Crommelin (1910a) then began a new study of the comet's motion using numerical integration, whereby the perturbed rectangular coordinates are obtained directly at each time step. This time they computed the perturbations from Venus through Neptune and used a time step that varied from 2 to 256 days. They predicted a 1910 perihelion passage time of April 17.11. The 1909 recovery of the comet required that their prediction be corrected by 3 days, and they then revised their work by reducing the time steps by one-half, carrying an additional decimal place and correcting certain errors in the previous work (Cowell and Crommelin, 1910b). Their post-recovery prediction was then revised to April 17.51 and they concluded that at least 2 days of the remaining discordance resulted from causes other than errors in the calculations or errors in the planetary positions and masses. We note here that the best predictions for the 1835 perihelion passage time by Rosenberger and de Pontécoulant as well as the 1910 prediction by Cowell and Crommelin were too early by 4.4, 3.5, and 2.7 days respectively.

In an attempt to account for this 4-day discrepancy between the actual period of Comet Halley and that computed from perturbations by the known planets, some unorthodox solutions have been proposed. Brady (1972) suggested the influence of a massive trans-Plutonian planet, and Rasmusen (1967) adjusted the sun:Jupiter mass ratio from the accepted value of 1047 to 1051. Both of these proposed solutions must be rejected because they would produce effects on the motion of the known planets that are not supported by observation. Rasmusen (1981) derived a 1986 perihelion date of February 5.46 from a fit to the observations in 1835 and 1910 and then added +3.96 days to yield a 1986 perihelion passage time prediction of February 9.42. Brady and Carpenter (1967) first suggested a 1986 perihelion passage time of February 5.37 based upon a "trial and error" fit to the observations during the 1835 and 1910 returns. Brady and Carpenter (1971) then introduced an empirical secular term in the radial component of the comet's equations of motion. Although this device had the unrealistic effect of decreasing the solar gravity with time, it did allow an accurate 1986 perihelion passage time prediction of February

9.39. It is now clear that the actual 1986 perihelion passage time was accurately predicted by both Rasmusen (1981) and Brady and Carpenter (1971). However, if the orbit of the comet is to be accurately computed throughout a particular apparition, or if the comet's motion is to be traced back to ancient times, the mathematical model used to represent the obvious non-gravitational forces must be based upon a realistic physical model and not upon empirical mathematical devices.

Marsden *et al.* (1973) developed a realistic model for the non-gravitational forces affecting the motions of comets by assuming that these forces were due to the rocket-like thrusting of a vapourizing water-ice nucleus, and Yeomans (1977) used this model to compute the orbit of Comet Halley over the 1607–1911 interval. The numerical integration was run back to A.D. 837 and forward to predict a 1986 perihelion passage time of February 9.66. It was this prediction that was used for the successful recovery of Comet Halley at Palomar on October 16, 1982 (Jewitt *et al.*, 1982). Subsequently, Yeomans (1984) modified his orbit-determination programs and provided an improved prediction of February 9.486. Using the same non-gravitational force model and a similar technique, Savchenko (1982) used the observations of Comet Halley over the 1682–1911 interval to provide a perihelion passage prediction of February 9.513.

By 1984, Comet Halley orbit computations based on observations over the interval 1835–1984 were predicting a perihelion passage time of 1986 February 9.45 when the non-gravitational force model of Marsden *et al.* (1973) was employed (Landgraf, 1984; Morley and Hechler, 1984; Yeomans, 1984). Using the same model over the 1682–1984 observed interval, Savchenko (1984) found February 9.47 while Landgraf (1984) suggested February 9.50–9.55 if a time dependent term was added to the expression for the transverse non-gravitational acceleration and observations over the 1607–1984 interval were employed.

I.2. *The Identification of Early Comet Halley Apparitions.* Until the 20th century, all attempts at identifying ancient apparitions of Comet Halley were made either by determining orbits directly from the observations or by stepping back in time at roughly 76-year intervals and testing the observations with an approximate orbit of Comet Halley. Pingré (1783–84) confirmed the suspicion of Halley (1705) by showing that the comet of 1456 was an earlier apparition of Comet Halley. Biot (1843) pointed out that an orbit by Burckhardt (1804) for the comet of 989 closely resembled that of Comet Halley, and Laugier (1843, 1846) correctly identified as Comet Halley the comets seen by the Chinese in 451, 760, and the autumn of 1378. Laugier (1842) also noted that four of the five parabolic orbital elements for the comet seen in 1301 were close to those of Comet Halley. By stepping backward in time at roughly 76–77 year intervals and analyzing European and Chinese observations, Hind (1850) attempted to identify Comet Halley apparitions from 11 B.C. to 1301. Approximate perihelion passage times were often determined directly from the observations, and an identification was suggested if Halley-like orbital elements could satisfy existing observations. Although many of Hind's identifications were correct, he was seriously in error for his suggested perihelion passage times in A.D., 1223, 912, 837, 608, 373 and 11 B.C.

Using a variation-of-elements technique, Cowell and Crommelin (1907d) began the first effort actually to integrate the comet's equations of motion backward in time. They assumed that the orbital eccentricity and inclination were constant with time and the argument of perihelion and the longitude of the ascending node changed uniformly with time – their rates being deduced from the values computed over the 1531–1910 interval. By using Hind's (1850) times of perihelion passage or by computing new values from the observations, they deduced preliminary values of the orbital major semi-axes for the perturbation calculations. The motion of the comet was accurately carried back to 1301 by taking into account first-order perturbations in the comet's period from the effects of Venus, Earth, Jupiter, Saturn, Uranus, and Neptune. Using successively more approximate perturbation methods, Cowell and Crommelin (1907d, 1908a–e) carried the motion of the comet back to 239 B.C. At this stage, their integration was in error by nearly 1.5 years in the perihelion passage time, and they adopted a time of May 15, 240 B.C., not from their integration, but rather from a consideration of the observations themselves.

According to Kamienski (1956), the perihelion passage times of Comet Halley were computed from 451 back to 622 B.C. by M.A. Viliev. Using Viliev's perihelion passage times from 622 B.C. to A.D. 451 and those of Cowell and Crommelin from 530 to 1910, Kamienski (1957) fitted a Fourier interpolation formula to the orbital periods, and, while the formula fits the data used to generate it, accurate extrapolation beyond the data arc is not possible. Much as Ångström's (1862) similar analysis failed to predict the 1910 perihelion passage time by 2.8 years, Kamienski's (1962) prediction for the 1986 perihelion passage is in error by 9 months. In the absence of a dynamical model for the comet's motion, it is unrealistic to investigate the past or future motion of Comet Halley by using such empirical devices.

After an analysis of the European and Chinese observations, Kiang (1972) used the variation-of-elements technique to investigate the motion of Comet Halley over the 240 B.C.–A.D. 1682 interval. By determining the time of perihelion passage directly from the observations and considering the perturbations from all nine planets on the other orbital elements, Kiang traced the motion of Comet Halley for nearly two millennia. Hasegawa (1979) also empirically determined perihelion passage times for Comet Halley. For each apparition from A.D. 1378 to 240 B.C., he computed several ephemerides using Kiang's (1972) orbital elements, except for the perihelion passage times, which were chosen to make the best fit with the observations.

Brady and Carpenter (1971) were the first to apply direct numerical integration to the study of Comet Halley's ancient apparitions. Using an empirical secular term to represent the non-gravitational effect, they initiated their integration with an orbit that was determined from the 1682 through 1911 observations and integrated the comet's motion back to A.D. 141 in one continuous run. Subsequently, Brady (1982) took the integration of Comet Halley back to 2647 B.C. Because the integration was tied to no observational data before 1682, the early perihelion dates diverged from the dates Kiang (1972) had determined directly from the Chinese observations. Using Brady and Carpenter's (1971) orbit for Comet Halley, Chang (1979) integrated the comet's motion back to 1057 B.C. However, this integration was not based upon any observations before 1909, nor were non-gravitational effects taken into account.

Yeomans and Kiang (1981) began their investigation of Comet Halley's past motion with an orbit based upon the 1759, 1682, and 1607 observations and numerically integrated the comet's motion back to 1404 B.C. An existing up-to-date planetary ephemeris was extended backward in time and the results checked against the planetary positions listed by Tuckerman (1964) and Stahlman and Gingerich (1963). Planetary and non-gravitational perturbations were taken into account at each integration step. In nine cases, the perihelion passage times calculated by Kiang (1972) from Chinese observations were redetermined and the unusually accurate observed perihelion times in A.D. 837, 374, and 141 were used to constrain the computed motion of the comet.

Landgraf (1984) integrated the motion of Comet Halley back to 2317 B.C. and obtained results very similar to those of Yeomans and Kiang (1981) back to 87 B.C., but the two sets of predicted perihelion passage times diverged rapidly before 87 B.C.

Because of repeated close approaches to the Earth, it is not possible to extrapolate the motion of Comet Halley substantially beyond the observation interval. Unavoidable errors in the comet's computed motion are usually increased considerably by a strong planetary perturbation so that the subsequent motion must be tied to observational data. Comet Halley's close approaches to the earth are given in section II. While Yeomans and Kiang

(1981) were able to use the ancient Chinese observations to rectify, or constrain, the integration of Comet Halley, they were forced to cease the integration back in time when the computed motion of the comet brought it within 0.03 A.U. of the Earth in 1404 B.C. An analysis by Stephenson *et al.* (1985) has shown that of the various attempts to extrapolate Halley's motion into the pre-Christian era, only the results of Yeomans and Kiang (1981) are consistent with recently discovered Babylonian observations of Comet Halley in both 87 B.C. and 164 B.C. and that the 240 B.C. apparition of the comet is the earliest for which observational evidence exists.

II. *The Observational History of Comet Halley.* II.1. *The Historical Records of Comet Halley: 240 B.C. through A.D. 1910.* Despite repeated attempts in the literature to link various historic occurrences to ancient apparitions of Comet Halley, there is no evidence for recorded apparitions before 240 B.C. While Comet Halley is the brightest periodic comet, in any given century there are always non-periodic comets that have been far brighter than Halley. In order to link an ancient phenomenon to a return of Comet Halley, the sighting must be properly dated and contain information on the object's celestial motion. The 466–467 B.C. apparition of a comet, and earlier apparitions as well, are often stated to be returns of Comet Halley, but a lack of quantitative information on these sightings makes an identification impossible (Stephenson and Yau, 1985). Likewise, it is not reasonable to date historical phenomena using the computed times for Comet Halley's apparitions unless there is quantitative information on the comet's motion in the sky.

Using the orbital elements of Comet Halley as given by Yeomans and Kiang (1981), figures 1–3 represent the viewing conditions of Comet Halley at each apparition from 240 B.C. to A.D. 1910. These figures are drawn in a rotating reference system so that, for a given apparition, the Earth and Sun positions remain fixed, and only the comet's apparent motion is depicted. The open circles on the comet's apparent path represent the comet's position before (−) or after (+) perihelion (P) in 40-day increments. The position of the vernal equinox (γ) is given for the perihelion passage time in each case. Because the comet's orbit has been projected onto the ecliptic plane, the viewing conditions can only be considered approximate. Using the 141 apparition in figure 1 as an example, we note that the comet was a difficult object for viewing a few weeks before perihelion (it was behind the sun) and that the comet passed close to the earth about a month after perihelion. Figure 4 plots the intervals, in years, between successive times of perihelion passage from 240 B.C. to A.D. 2061.

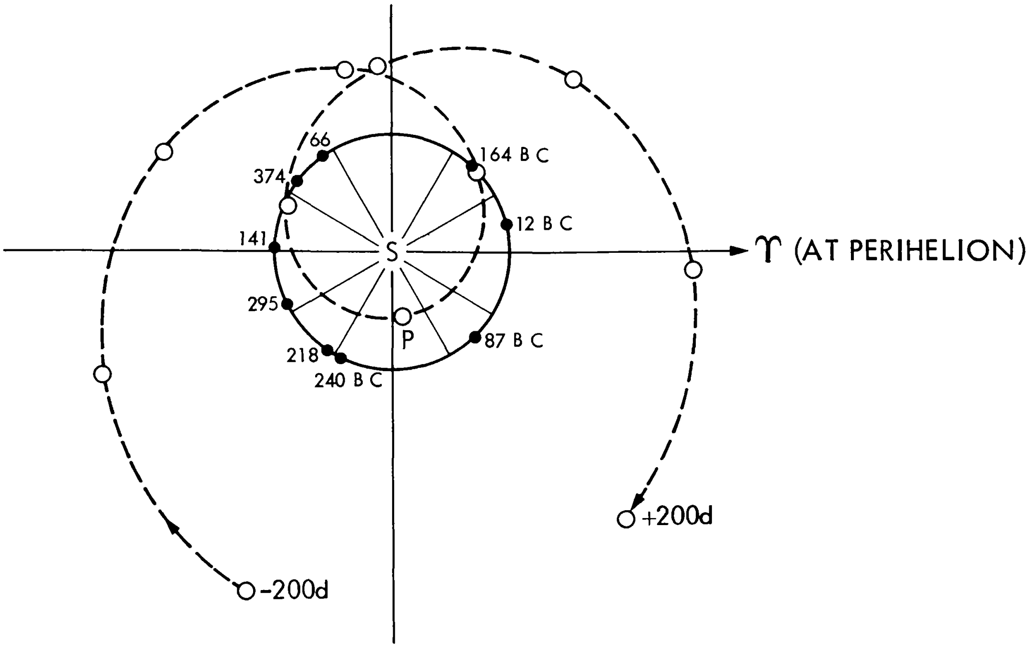

FIG. 1—Comet Halley Viewing Conditions for Apparitions 240 B.C. – A.D. 374.
This figure is drawn in a rotating reference system so that, for a given apparition, the earth and sun (S) positions remain fixed, and only the comet's apparent motion is depicted. The open circles on the comet's apparent path represent the comet's position before (−) and after (+) perihelion (P) in 40 day increments. The position of the vernal equinox (♈) is given for the perihelion passage time in each case. Because the comet's orbit plane has been projected onto the ecliptic plane, the viewing conditions can only be considered approximate. A viewer located on earth would see the comet make the indicated looped motion with respect to his position and that of the sun.

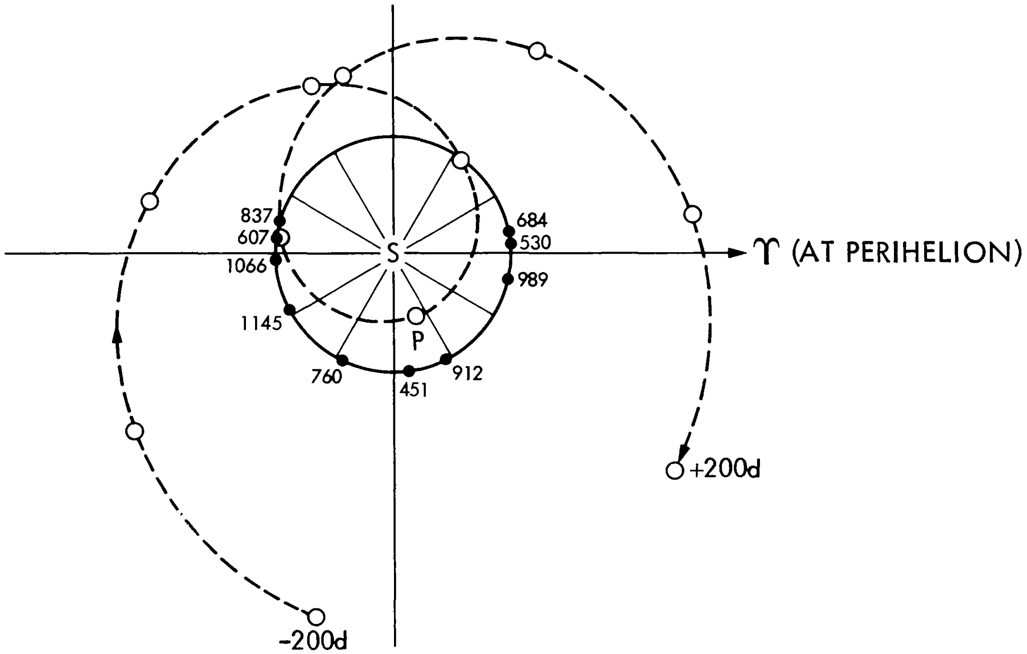

FIG. 2—Comet Halley Viewing Conditions for Apparitions 451–1145.
The explanation given for figure 1 applies.

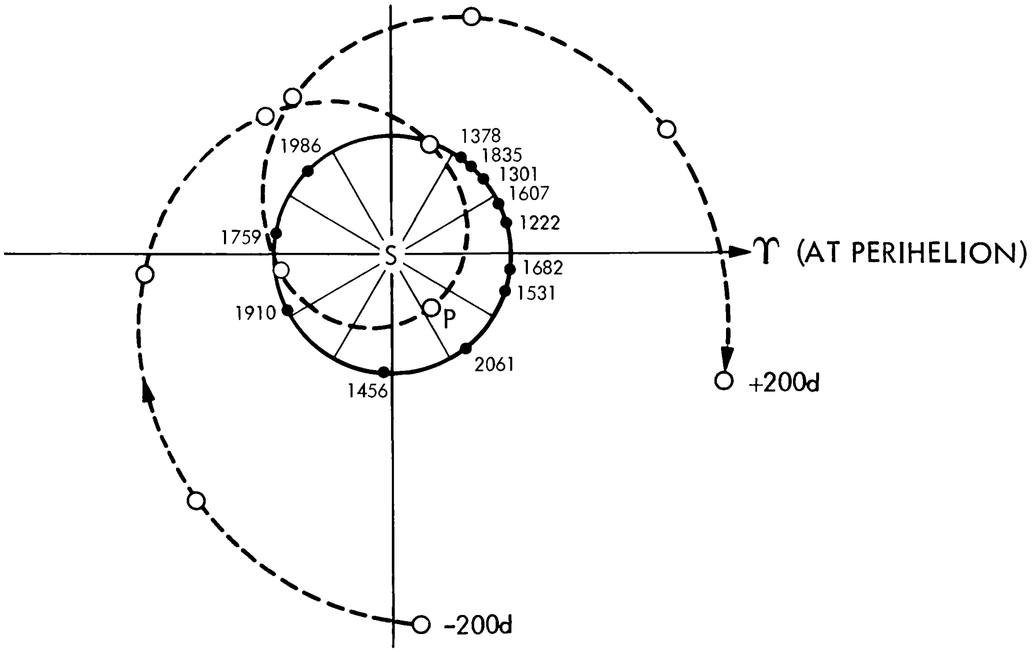

FIG. 3—Comet Halley Viewing Conditions for Apparitions 1222–2061. The explanation given for figure 1 applies.

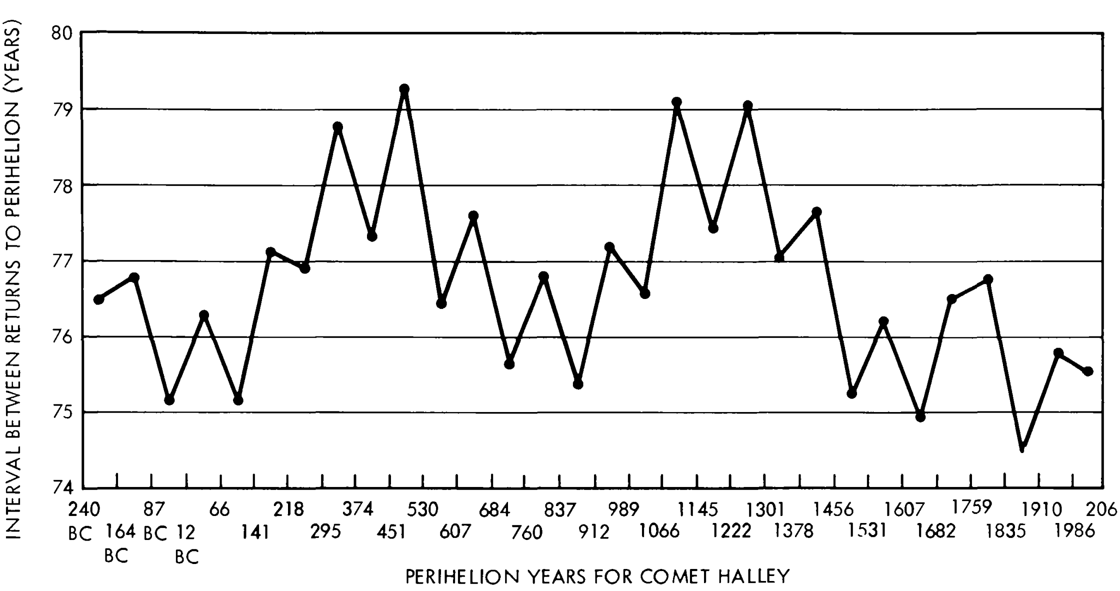

FIG. 4—The interval between successive perihelion-passage times for Comet Halley is plotted against the perihelion years. The minimum and maximum intervals are 74.42 years (1835–1910) and 79.25 years (451–530).

Table I provides a listing of the comet's perihelion passage times, the observed intervals, selected ephemeris positions, earth-comet and sun-comet distances in A.U., apparent magnitudes, tail position angles, and solar elongation angles in degrees. The following notes on Comet

Halley observations are meant to provide a guide as to where comprehensive observations were made and what records are extant. The perihelion passage (*P*) time, as given by Yeomans and Kiang (1981) is supplied after each apparition year. Also given is the minimum distance (*d*) between the comet and Earth and the approximate date on which this close approach occurred. For the early apparitions, the countries where quantitative observations were recorded are noted; for the more recent apparitions, the records are too numerous to mention in detail. No attempt has been made at completeness, and, for the early apparitions, we have relied upon the comprehensive observation summaries given by Stephenson and Yau (1985).

Chinese observers had different names for different cometary forms. One of these is the "po" (sparkling) comet, signifying a symmetric, diffuse image without a tail. A "hui" comet or broom star is one with a tail. We have adopted the po-comet and broom-star designations. When noting the angular length of a comet's tail, the Chinese usually used a linear unit of measure termed a "chih" (foot). We have assumed that 1 chih is approximately 1.5 degrees (Kiang, 1972). Dates before 1582 are referred to the Julian calendar. Although the perihelion passage times and Earth close-approach times are Greenwich mean times, the Chinese dates of observation have been left in terms of the reported local times.

TABLE I

COMET HALLEY EPHEMERIDES 240 B.C. TO A.D. 1911.

For each apparition, the observed interval and perihelion passage time (*P*) are given. For each ephemeris date listed, the right ascension (RA) and declination (Dec) are given in hours and minutes and degrees and arc minutes respectively. RA and Dec are referred to the equinox of 1950. The earth-comet distance (*D*) and sun-comet distance (*r*) are given in A.U., the total magnitude estimates (M_1) were determined using the formulae of Bortle and Morris (1984), and the entries TPA and EL refer to the position angle (east of north) of the extended heliocentric radius vector and the solar elongation angle in degrees.

	Obs. Interval	Ephemeris Positions									
Apparition	Perihelion (*P*)	Date	RA		Dec		*D*	*r*	M_1	TPA	EL
240 B.C.	May–June	5/6	2	26.1	+20	05	1.37	0.72	4.6	255	31
	P = May 25.1	5/16	2	41.0	+25	17	1.00	0.62	3.2	259	36
		5/26	3	46.0	+36	25	0.62	0.59	0.3	275	31
		6/5	8	4.3	+41	24	0.46	0.63	−0.1	34	25
		6/15	10	42.9	+19	48	0.71	0.74	1.4	95	47
		6/25	11	23.5	+ 9	21	1.07	0.88	2.8	104	50
164 B.C.	Oct.–Nov.	10/14	19	7.0	−14	36	0.56	0.86	3.5	91	60
	P = Nov. 12.6	10/24	18	45.4	−15	33	0.90	0.72	3.7	90	45
		11/3	18	29.0	−16	16	1.21	0.62	3.6	87	31
		11/13	18	11.7	−17	7	1.45	0.58	2.1	78	17

TABLE I (*continued*)

Apparition	Obs. Interval Perihelion (P)	Ephemeris Positions Date	RA		Dec		D	r	M_1	TPA	EL
87 B.C.	July 9–Aug. 24	7/8	5	11.4	+28	29	0.99	0.86	4.7	258	51
	P = Aug. 6.5	7/18	6	27.6	+35	38	0.62	0.72	2.9	272	45
		7/28	10	23.8	+33	4	0.44	0.62	1.4	4	22
		8/7	12	59.9	+ 9	12	0.68	0.59	0.5	92	34
		8/17	13	36.2	− 1	8	1.07	0.63	1.7	102	35
		8/27	13	45.3	− 5	41	1.44	0.73	2.9	105	29
12 B.C.	Aug. 26–Oct. 20	8/22	6	7.0	+24	19	0.76	1.17	5.6	259	82
	P = Oct. 10.8	9/1	6	56.6	+30	54	0.38	1.01	3.5	264	81
		9/6	8	40.5	+39	8	0.22	0.94	1.8	281	67
		9/11	13	39.4	+26	31	0.17	0.86	0.9	27	34
		9/21	16	21.9	− 5	59	0.49	0.73	2.4	92	44
		10/1	16	39.5	−11	52	0.88	0.63	2.9	94	39
		10/11	16	36.5	−14	25	1.24	0.59	1.8	92	28
		10/21	16	26.8	−16	7	1.52	0.63	2.5	87	16
A.D. 66	Jan. 31–Apr. 10	1/31	21	15.2	− 9	20	1.44	0.60	2.2	281	19
	P = Jan. 26.0	2/10	20	56.8	−10	48	1.23	0.67	2.2	273	33
		2/20	20	37.4	−12	41	0.96	0.79	2.3	270	48
		3/2	20	8.3	−15	44	0.67	0.94	2.0	270	65
		3/12	18	53.2	−22	15	0.38	1.09	1.3	276	93
		3/22	14	20.7	−24	16	0.25	1.25	0.9	324	162
		4/1	11	24.2	− 7	47	0.48	1.40	2.7	98	139
		4/11	10	41.5	− 2	4	0.80	1.55	4.1	102	117
141	Mar. 27–late Apr.	3/23	23	40.8	+ 6	40	1.20	0.58	1.7	264	29
	P = Mar. 22.4	4/2	23	38.7	+ 8	56	0.84	0.63	1.2	262	38
		4/12	0	1.5	+16	18	0.45	0.73	0.3	265	41
		4/17	0	54.5	+27	45	0.27	0.80	−0.5	279	33
		4/20	2	34.7	+40	55	0.19	0.84	−1.0	326	25
		4/22	4	53.1	+46	32	0.17	0.87	−1.2	27	32
		4/24	7	11.3	+40	58	0.19	0.90	−0.8	68	50
		4/27	8	51.7	+27	54	0.27	0.95	0.1	92	68
		5/2	9	46.8	+16	24	0.44	1.02	1.4	101	79
218	early May–mid June	5/3	2	4.9	+19	45	1.31	0.67	4.1	258	30
	P = May 17.7	5/13	2	19.9	+24	59	0.93	0.59	2.8	261	35
		5/23	3	35.8	+36	43	0.56	0.59	0.1	282	29
		6/2	8	16.5	+37	51	0.44	0.67	0.0	58	29
		6/12	10	34.5	+16	52	0.72	0.80	1.6	101	51
		6/22	11	11.4	+ 7	44	1.09	0.94	3.1	108	53
295	May 1–30	5/1	1	36.7	+25	52	0.57	0.62	0.3	269	34
	P = Apr. 20.4	5/11	5	30.2	+42	45	0.32	0.73	−0.4	19	23
		5/16	8	24.3	+32	37	0.38	0.80	0.2	81	45
		5/26	10	12.6	+14	9	0.70	0.95	2.2	104	64
		6/5	10	42.3	+ 7	20	1.07	1.10	3.6	108	64

TABLE I (*continued*)

	Obs. Interval	Ephemeris Positions									
Apparition	Perihelion (*P*)	Date	RA		Dec		*D*	*r*	M_1	TPA	EL
374	Mar. 4–Apr. 2	3/4	21	49.5	− 5	58	1.02	0.67	1.8	265	39
	P = Feb. 16.3	3/14	21	34.7	− 7	42	0.69	0.80	1.6	263	53
		3/24	21	4.9	−11	55	0.34	0.95	0.6	262	70
		3/29	20	4.7	−19	42	0.17	1.02	−0.6	267	91
		4/1	17	26.6	−31	13	0.09	1.07	−1.8	289	130
		4/2	15	39.7	−31	43	0.09	1.09	−1.9	313	152
		4/3	13	59.5	−26	59	0.10	1.10	−1.6	15	166
		4/8	11	11.9	− 7	25	0.24	1.18	0.6	100	131
451	June 10–Aug. 15	6/9	3	48.0	+27	34	1.12	0.71	4.1	260	38
	P = June 28.2	6/19	4	41.7	+35	10	0.74	0.61	2.4	271	37
		6/29	8	2.3	+40	17	0.49	0.57	−0.3	351	20
		7/9	11	12.7	+18	16	0.66	0.62	0.6	93	36
		7/19	12	3.3	+ 5	34	1.03	0.73	2.1	106	42
		7/29	12	20.8	− 0	6	1.40	0.87	3.4	110	38
		8/8	12	29.8	− 3	21	1.73	1.03	4.4	113	32
		8/18	12	36.1	− 5	36	2.02	1.18	5.2	117	25
530	Aug. 29–Sep. 23	8/29	8	49.2	+37	27	0.35	0.85	2.4	292	54
	P = Sep. 27.1	9/3	11	51.7	+31	8	0.28	0.78	1.5	352	32
		9/8	14	8.8	+12	5	0.36	0.71	1.6	66	30
		9/13	15	5.7	+ 0	25	0.53	0.65	2.0	87	37
		9/23	15	40.0	− 8	58	0.92	0.58	2.7	94	35
607	Mar.–Apr.	3/11	23	21.3	+ 3	12	1.42	0.59	3.7	268	20
	P = Mar. 15.5	3/21	23	10.6	+ 3	14	1.12	0.59	1.6	262	32
		3/31	23	7.1	+ 4	2	0.76	0.67	1.2	260	42
		4/10	23	23.7	+ 8	1	0.37	0.80	0.2	259	46
		4/15	0	10.9	+16	33	0.19	0.87	−1.0	265	38
		4/19	4	15.6	+37	36	0.09	0.93	−2.3	35	25
		4/20	6	16.3	+35	16	0.10	0.95	−2.2	71	45
		4/25	9	28.1	+13	23	0.25	1.02	0.2	103	85
		5/5	10	11.6	+ 5	27	0.63	1.18	2.7	107	89
684	Sep.–Oct.	9/3	9	25.7	+39	40	0.30	0.86	2.1	301	54
	P = Oct. 2.8	9/8	12	51.6	+28	4	0.26	0.79	1.4	16	31
		9/13	14	47.7	+ 8	13	0.37	0.72	1.8	74	34
		9/23	15	50.6	− 7	5	0.75	0.62	2.5	91	38
		10/3	15	59.7	−12	11	1.13	0.58	1.6	93	31
		10/13	15	55.0	−14	54	1.45	0.62	2.3	92	20
760	May 17–mid July	5/16	2	20.4	+25	8	0.94	0.59	2.8	263	35
	P = May 20.7	5/26	3	34.7	+35	54	0.55	0.59	0.1	282	29
		6/5	8	12.1	+36	23	0.43	0.67	−0.1	63	28
		6/15	10	33.6	+15	8	0.70	0.80	1.6	104	51
		6/25	11	11.4	+ 6	8	1.07	0.94	3.1	110	54
		7/5	11	28.2	+ 1	47	1.43	1.10	4.2	113	50
		7/15	11	38.8	− 0	54	1.77	1.25	5.1	115	44

TABLE I (*continued*)

Apparition	Obs. Interval	Ephemeris Positions									
	Perihelion (*P*)	Date	RA		Dec		*D*	*r*	M_1	TPA	EL
837	Mar. 22–Apr. 28	3/21	22	11.6	−3	54	0.76	0.74	1.5	259	47
	P = Feb. 28.3	3/31	22	1.7	−6	4	0.40	0.87	0.7	257	60
		4/5	21	50.2	−9	32	0.21	0.95	−0.4	256	68
		4/9	20	53.3	−25	29	0.07	1.01	−2.7	260	89
		4/10	19	5.2	−44	5	0.04	1.03	−3.8	282	115
		4/11	13	25.3	−42	58	0.04	1.04	−3.9	34	149
		4/15	10	40.9	−6	32	0.17	1.10	−0.4	102	119
		4/25	10	23.9	−0	35	0.54	1.26	2.6	106	104
912	July	7/4	5	18.3	+35	42	0.76	0.66	2.9	274	41
	P = July 18.7	7/14	8	27.8	+39	55	0.49	0.59	1.4	339	23
		7/24	11	45.8	+16	44	0.64	0.59	0.4	91	33
		8/3	12	38.6	+2	56	1.00	0.67	1.8	106	39
989	Aug.–Sep.	8/2	5	58.0	+30	47	0.89	0.93	4.9	268	58
	P = Sep. 5.7	8/12	7	29.6	+37	31	0.54	0.79	3.0	286	51
		8/17	9	25.3	+38	24	0.41	0.72	2.0	317	37
		8/22	11	52.5	+27	38	0.40	0.67	1.5	24	24
		9/1	14	7.2	+2	30	0.68	0.59	2.1	91	35
		9/11	14	36.0	−6	48	1.07	0.59	1.5	99	33
		9/21	14	40.3	−10	57	1.43	0.67	2.6	101	25
1066	Apr. 3–June 7	3/31	23	17.6	+4	17	0.93	0.62	1.4	259	37
	P = Mar. 20.9	4/10	23	25.1	+5	47	0.55	0.72	0.7	257	44
		4/20	0	54.3	+16	10	0.18	0.86	−1.1	263	30
		4/25	6	48.1	+23	28	0.12	0.94	−1.7	89	49
		4/30	9	21.0	+9	32	0.28	1.01	0.4	105	83
		5/10	10	9.1	+3	35	0.65	1.17	2.7	109	86
		5/20	10	23.8	+1	46	1.03	1.33	4.1	110	81
		5/30	10	33.0	+0	40	1.39	1.48	5.2	112	74
		6/9	10	40.7	−0	14	1.74	1.63	6.0	114	67
1145	Apr. 15–July 6	4/14	0	40.0	+12	57	1.23	0.58	3.3	261	28
	P = Apr. 18.6	4/24	0	46.0	+15	50	0.85	0.59	1.0	260	36
		5/4	1	39.6	+24	36	0.45	0.67	0.1	269	31
		5/9	3	23.4	+33	55	0.30	0.73	−0.5	311	17
		5/14	6	52.9	+33	25	0.28	0.80	−0.4	73	33
		5/19	9	2.1	+20	16	0.39	0.87	0.6	101	57
		5/29	10	16.7	+7	49	0.75	1.02	2.6	110	69
		6/8	10	40.8	+3	19	1.12	1.18	3.9	112	66
		6/28	11	3.8	−0	47	1.83	1.49	5.8	116	55
		7/8	11	12.0	−2	9	2.14	1.64	6.4	118	48
1222	Sep. 3–Oct. 8	8/30	8	13.8	+38	37	0.43	0.86	2.9	291	58
	P = Sep. 28.8	9/4	10	41.9	+37	55	0.32	0.79	1.9	330	41
		9/9	13	22.0	+21	23	0.34	0.72	1.6	41	29
		9/14	14	40.5	+5	50	0.48	0.66	1.9	78	34

TABLE I (*continued*)

	Obs. Interval	Ephemeris Positions									
Apparition	Perihelion (*P*)	Date	RA		Dec		*D*	*r*	M_1	TPA	EL
1222		9/24	15	29.2	− 7	18	0.86	0.58	2.6	91	36
		10/4	15	35.9	−12	22	1.24	0.59	1.8	94	28
		10/14	15	31.6	−15	10	1.54	0.66	2.7	94	17
1301	Sep. 1–Oct. 31	9/1	6	17.3	+26	59	0.90	1.24	6.3	268	81
	P = Oct. 25.6	9/11	6	49.1	+32	54	0.53	1.09	4.5	272	84
		9/16	7	34.6	+39	48	0.35	1.01	3.2	278	81
		9/21	10	20.2	+50	5	0.21	0.93	1.7	314	65
		9/26	15	1.7	+25	43	0.21	0.85	1.3	45	43
		10/1	16	21.8	+ 3	37	0.36	0.78	2.1	76	45
		10/11	16	56.9	− 9	21	0.74	0.66	2.8	84	41
		10/21	16	58.5	−13	53	1.11	0.58	3.1	85	32
		10/31	16	49.6	−16	34	1.42	0.59	2.1	83	20
1378	Sep. 26–Oct. 11	9/22	6	23.7	+33	24	0.46	1.17	4.5	267	100
	P = Nov. 10.7	9/27	6	37.5	+43	39	0.28	1.09	3.1	265	102
		10/2	10	0.1	+77	50	0.13	1.01	1.1	298	92
		10/7	17	39.7	+21	5	0.18	0.93	1.4	69	65
		10/12	17	55.2	+ 0	16	0.35	0.86	2.5	77	58
		10/22	17	58.5	−10	19	0.72	0.72	3.2	81	47
		11/1	17	52.1	−14	11	1.07	0.61	3.3	80	35
		11/11	17	39.9	−16	40	1.37	0.58	2.0	78	21
		11/21	17	25.3	−18	43	1.58	0.62	2.5	63	8
1456	May 27–July 8	5/26	2	49.1	+25	9	1.20	0.66	3.9	264	34
	P = June 9.6	6/5	3	22.2	+31	29	0.80	0.59	2.4	271	35
		6/15	5	52.9	+41	23	0.48	0.59	−0.2	324	21
		6/20	8	22.2	+36	15	0.45	0.62	−0.2	55	22
		6/25	10	2.9	+23	30	0.54	0.67	0.5	95	37
		7/5	11	17.1	+ 7	46	0.88	0.80	2.1	110	49
		7/15	11	41.9	+ 1	13	1.26	0.94	3.4	114	48
1531	Aug. 1–Sep. 8	7/28	5	47.7	+33	10	0.91	0.85	4.5	274	52
	P = Aug. 26.2	8/7	7	32.2	+39	53	0.56	0.72	2.6	296	43
		8/12	9	33.1	+38	50	0.46	0.66	1.8	334	31
		8/17	11	43.3	+26	46	0.46	0.62	1.4	42	24
		8/22	12	59.7	+12	34	0.58	0.59	1.7	82	31
		9/1	13	53.8	− 2	22	0.95	0.60	1.3	99	35
		9/11	14	6.2	− 8	24	1.33	0.68	2.4	104	30
1607	Sep. 21–Oct. 26	9/18	7	9.3	+37	4	0.52	1.01	4.1	279	76
	P = Oct. 27.5	9/23	8	26.5	+44	1	0.35	0.93	2.8	293	68
		9/28	11	48.7	+44	7	0.25	0.86	1.7	345	49
		10/3	14	46.5	+19	49	0.30	0.79	1.7	52	38
		10/8	15	49.0	+ 3	16	0.45	0.72	2.2	76	41
		10/13	16	13.4	− 4	37	0.64	0.66	2.5	83	41
		10/18	16	23.6	− 8	59	0.83	0.62	2.8	85	38
		10/28	16	26.0	−13	49	1.20	0.58	1.7	87	29

TABLE I (*continued*)

Apparition	Obs. Interval Perihelion (P)	Ephemeris Positions									
		Date	RA		Dec		D	r	M_1	TPA	EL
1682	Aug. 15–Sep. 21	8/12	5	51.0	+32	38	0.97	0.93	5.0	274	56
	P = Sep. 15.3	8/17	6	19.5	+35	38	0.79	0.85	4.2	279	55
		8/22	7	10.7	+39	19	0.62	0.78	3.2	290	51
		8/27	8	48.6	+41	27	0.48	0.72	2.3	315	41
		9/1	11	10.2	+34	4	0.42	0.66	1.6	8	27
		9/6	12	54.8	+18	21	0.49	0.62	1.6	65	28
		9/11	13	46.6	+ 6	12	0.65	0.59	2.0	87	34
		9/21	14	22.5	− 5	36	1.03	0.60	1.5	98	34
1759 I	1758 Dec. 25– 1759 June 22	12/24	0	58.7	+ 7	55	1.09	1.61	8.0	67	102
		1/13	23	55.9	+ 3	45	1.37	1.31	7.5	65	65
	P = Mar. 13.1	2/2	23	21.9	+ 1	43	1.60	1.00	6.5	60	37
		2/22	22	54.9	+ 0	3	1.66	0.72	5.0	33	11
		3/14	22	24.8	− 2	50	1.41	0.58	2.1	268	20
		4/3	22	0.0	− 8	8	0.83	0.74	1.7	254	46
		4/13	21	48.3	−14	23	0.49	0.88	1.1	251	61
		4/18	21	36.0	−22	14	0.32	0.95	0.5	249	71
		4/23	20	47.5	−45	27	0.17	1.03	−0.7	256	93
		4/28	11	57.6	−53	32	0.14	1.11	−0.8	53	131
		5/3	10	42.4	−22	55	0.28	1.18	1.0	95	122
		5/13	10	25.4	− 9	30	0.64	1.34	3.1	107	106
		6/2	10	27.0	− 4	34	1.35	1.64	5.4	112	87
		6/22	10	36.4	− 3	57	2.03	1.93	6.9	116	70
1835 III	1835 Aug. 5– 1836 May 19	8/4	5	34.0	+22	9	2.50	1.98	10.7	266	49
		8/24	5	50.4	+23	51	1.87	1.69	9.4	269	64
	P = Nov. 16.4	9/13	6	9.2	+27	13	1.17	1.39	7.4	271	79
		9/23	6	23.5	+31	5	0.80	1.24	6.0	272	86
		10/3	6	59.7	+41	10	0.44	1.08	4.1	276	89
		10/8	8	15.9	+54	30	0.27	1.01	2.7	289	84
		10/11	11	14.0	+63	5	0.20	0.96	1.8	330	74
		10/13	14	8.0	+55	0	0.19	0.93	1.5	15	64
		10/18	16	35.5	+17	41	0.27	0.86	1.9	63	53
		10/23	17	7.4	+ 1	35	0.44	0.79	2.5	74	50
		11/2	17	22.4	− 9	35	0.81	0.67	3.1	79	42
		11/22	17	9.1	−17	12	1.45	0.60	2.2	78	18
		12/12	16	45.9	−21	29	1.76	0.80	3.6	284	8
	1836	1/1	16	25.6	−25	1	1.79	1.10	4.7	275	33
		1/21	15	59.2	−28	32	1.65	1.41	5.4	277	59
		2/10	15	10.9	−31	56	1.43	1.71	5.7	286	88
		3/1	13	43.8	−32	36	1.27	1.99	6.0	307	123
		3/21	12	0.0	−26	16	1.32	2.27	6.5	4	155
		4/10	10	51.9	−17	4	1.65	2.53	7.3	81	143
		5/20	10	11.3	− 7	3	2.73	3.02	9.0	109	97

TABLE I (*continued*)

	Obs. Interval	Ephemeris Positions									
Apparition	Perihelion (P)	Date	RA		Dec		D	r	M_1	TPA	EL
1910 II	1909 Aug. 25–	8/24	6	15.0	+17	16	4.08	3.63		267	57
	1911 June 16	10/3	6	20.0	+17	2	2.94	3.18		272	95
	P = Apr. 20.2	11/12	5	33.4	+16	47	1.83	2.70		277	145
		12/2	4	28.3	+15	57	1.46	2.44	10.6	9	174
		12/22	3	1.6	+13	25	1.36	2.18	9.9	70	137
	1910	1/11	1	50.1	+10	24	1.49	1.90	9.4	69	99
		1/31	1	7.7	+ 8	39	1.70	1.61	8.9	67	68
		2/20	0	44.1	+ 8	8	1.86	1.31	8.1	64	42
		3/12	0	28.0	+ 8	12	1.89	1.00	6.9	53	19
		4/1	0	11.2	+ 8	17	1.69	0.72	5.0	298	8
		4/21	23	53.7	+ 8	0	1.18	0.59	1.7	261	30
		5/1	23	54.8	+ 8	22	0.81	0.63	1.1	257	39
		5/11	0	27.0	+10	58	0.42	0.74	0.2	255	40
		5/16	1	36.0	+15	27	0.24	0.81	−0.7	258	27
		5/21	5	38.1	+18	51	0.15	0.88	−1.4	97	26
		5/26	8	52.1	+ 7	35	0.27	0.95	0.1	110	69
		5/31	9	47.2	+ 2	48	0.45	1.03	1.5	112	79
		6/10	10	22.9	− 0	27	0.83	1.18	3.3	113	79
		7/20	11	3.9	− 4	31	2.21	1.78	6.8	121	53
		8/29	11	31.5	− 8	2	3.23	2.33	8.5	138	24
		10/18	11	58.8	−12	46	3.86	2.96	9.7	264	23
		11/27	12	7.4	−16	21	3.86	3.43		285	57
	1911	1/6	11	52.0	−18	34	3.59	3.87		298	99
		2/15	11	6.2	−17	10	3.44	4.28		328	145
		3/27	10	15.4	−11	46	3.81	4.68		75	147
		5/6	9	51.3	− 6	46	4.68	5.06		105	107
		6/20	9	53.3	− 4	25	5.82	5.47		118	65

240 B.C. (P = May 25.1, d = 0.45 on June 4) China.
A broom star first appeared in the east, then at the north. During the month May 24–June 23, it was seen in the west.

164 B.C. (P = November 12.6, d = 0.11 on September 29) Babylonia.
According to Stephenson *et al.* (1985), recent analysis of Babylonian tablets in the British Museum suggests that Comet Halley was seen in the east before the lunar month beginning October 21 and in the west while in Sagittarius during the period October 21–November 19. The motion of the comet as computed by Yeomans and Kiang (1981) is consistent with these observations. No Chinese records of this apparition have been found.

87 B.C. (P = August 6.5, d = 0.44 on July 27) China.
A medieval Chinese encyclopedia states that a po comet appeared in the east during the month August 10–September 8. Kiang (1972) noted that Halley would have been seen in the west during that time and suggested that the month may have been incorrectly

transcribed in the secondary Chinese source. The comet would have been seen in the east in the previous month. Since the motion of Comet Halley in 87 B.C. is quite well established from orbit extrapolations, it seems likely that Halley was indeed the comet referred to in the Chinese medieval source. Stephenson *et al.* (1985) note that according to Babylonian records, a comet was visible "day beyond day" during the lunar month July 14–August 11, and a reasonable interpretation of those records suggests that the comet was last seen on August 24. The motion of the comet as given by Yeomans and Kiang (1981) indicates that the comet's solar elongation on August 24 was only 31 degrees and decreasing with time. The Babylonian account also records the first quantitative measurement of the comet's tail noting that it was observed to be 4 cubits in length (approximately 10 degrees).

12 B.C. (P = October 10.8, d = 0.16 on September 10) China.
The comet was extensively observed in China for 56 days. It was first seen on August 26 as a po comet.

A.D. 66 (P = January 26.0, d = 0.25 on March 20) China.
Comet Halley was first sighted in the east on January 31, again on February 20, and finally about April 10 when it was 1.54 and 0.77 A.U. from the sun and earth respectively. Hence the comet was visible to the naked eye for some 74 days after perihelion.

A.D. 141 (P = March 22.4, d = 0.17 on April 22) China.
On March 27, a broom star was seen in the east with a tail about 9 degrees long and pale blue in color; this was certainly the CO^+ ion tail. The comet was observed until late April.

A.D. 218 (P = May 17.7, d = 0.42 on May 30) China.
The comet was seen for approximately 40 days from early May to mid-June. For the first 20 days, it was described as a bushy comet seen in the east.

A.D. 295 (P = April 20.4, d = 0.32 on May 12) China.
Observed during the month of May, the comet began as a po comet and later became a broom star in the west. Apparently the Chinese recognized that the comet seen in early May on the eastern horizon was the same object seen later that month on the western horizon.

A.D. 374 (P = February 16.3, d = 0.09 on April 2) China.
The Chinese observational records are remarkably brief considering that the comet made a close earth approach near opposition in early April.

A.D. 451 (P = June 28.2, d = 0.49 on June 30) China.
The comet is described as a broom star in July and August; when the comet was last seen on August 15, it was 48 days past perihelion.

A.D. 530 (P = September 27.1, d = 0.28 on September 3) China.
On August 29, a broom star was seen in the northeast morning sky, and its pure white (dust) tail was reported to be 9 degrees long. On September 4, the comet was seen as a northwest evening object with a 1° tail pointing to the southeast. On September 23, the comet was barely visible, and 4 days later it could not be seen (in the evening twilight?).

A.D. 607 (P = March 15.5, d = 0.09 on April 19) China.
Three separate apparitions of a comet-like object result in a confusing set of observations. Stephenson and Yau (1985) suggest that Halley was first recorded on March 30 or April 18 and was followed for 20 days.

A.D. 684 (P = October 2.8, d = 0.26 on September 7) China, Japan.
On September 6 or 7, a broom star was seen in the west with a tail more than 15 degrees long. It was observed for approximately 33 days. Subsequent observations recorded in November are not consistent with Comet Halley's motion or observability.

A.D. 760 (P = May 20.7, d = 0.41 on June 3) China.
During this apparition, the comet was first seen in the eastern sky before dawn on May 17 with a white tail some 6° long. It was observed for approximately 50 days thereafter. Another comet seems to have been observed at almost the same time in the south or west beginning on May 21.

A.D. 837 (P = February 28.3, d = 0.04 on April 11) China, Japan.
It is fortunate that this apparition, during which Comet Halley made its closest approach to the earth, is covered by the most detailed set of observations preserved in the Far-Eastern records. On the night of March 22, a broom star appeared in the east with a 11.° tail pointing west. On the night of April 6, the 15° tail pointed slightly south while on the evening of April 11, the 76° tail pointed north. Two nights later the tail reached its maximum length of 93° and pointed east. Thus, in a few weeks' time, the Chinese reported the tail pointing in all four directions.

A.D. 912 (P = July 18.7, d = 0.49 on July 16) China, Japan.
The Chinese observations are discordant, but contemporary Japanese observations during the second half of July are reasonably consistent with Halley's motion.

A.D. 989 (P = September 5.7, d = 0.39 on August 20) China, Japan, Korea.
On August 12-13, a bluish white broom stair appeared. In the morning, it was seen at the northeast for 10 days. Later, in the evening, it was seen at the northwest and after 30 days it disappeared.

A.D. 1066 (P = March 20.9, d = 0.11 on April 24) China, Japan, Korea, Europe.
Comprehensive Chinese observations allow the comet to be placed as a morning object in the east during the interval April 3-22 and, after conjunction as a western, evening object from April 24 through June 6. The comet was last observed 77 days from perihelion, suggesting an unusually bright post-perihelion apparition. According to an 11th-century manuscript in the archives of the cathedral in Viterbo, Italy, the comet was observed in the east by a cleric for 15 days beginning on April 5. Reappearing in the western, evening sky on April 24, "it looked like an eclipsed moon, its tail rose like smoke halfway to the zenith, and it kept shining to about the beginning of June" (Stein, 1910).

A.D. 1145 (P = April 18.6, d = 0.27 on May 12) China, Japan, Korea, Europe.
As at the previous return, the observed period during this apparition is extraordinary. According to Pingré (1783), Europeans first sighted the comet on April 15. In China, it was apparently seen from April 26 until July 6 when it was 78 days past perihelion. When first

sighted, the comet was described as a broom star in the east; by June 4, it was characterized as a pale blue guest star.

A.D. 1222 (P = September 28.8, d = 0.31 on September 6) China, Japan, Korea.
Korean observers first discovered the comet before solar conjunction on September 3. The discovery observations describe the comet as a broom star, with a tail more than 5° long, pointing west. After the comet reached conjunction on September 5, Japanese observers described it as a broom star seen in the northwest. On September 8, its centre was as large as a half-moon and white in colour. However, the tail rays were red and more than 25° long.

A.D. 1301 (P = October 25.6, d = 0.18 on September 23) China, Japan, Korea, Europe.
Pingré (1783) notes that Europeans first discovered the comet on September 1. If so, this would imply that the comet was already unusually bright. Thorndike (1950) notes that the French cleric Peter of Limoges (Petrus Lacepiera) made observations with respect to the stars during the interval September 30–October 6. Korean observers first sighted the broom star on September 14. Chinese observers followed the comet from September 16 to October 31, describing it as white in colour. On September 23, Japanese observers noted its tail was longer than 15°.

A.D. 1378 (P = November 10.7, d = 0.12 on October 3) China, Japan, Korea.
The Chinese discovered the comet on September 26, and, a week later, Korean observers noted that its position was less than 10° from the north celestial pole. These same observers were still offering prayers against the comet on November 15, so it may have been followed until then. However, Chinese observers recorded it only through October 11.

A.D. 1456 (P = June 9.6, d = 0.45 on June 19) China, Japan, Korea, Europe.
The Chinese first observed the comet on May 27 in the northeast with a 3° tail pointing southwest. By June 7, the tail length had increased to over 15°, and on June 22 the comet was seen in the northwest with a tail more than 13° long. The Italian Toscanelli observed the comet from June 8 to July 8, and Peurbach, in Vienna, tried to measure the comet's parallax – the first attempt of its kind (Hellman,. 1944; Jervis, 1978).

A.D. 1531 (P = August 26.2, d = 0.44 on August 14).
On August 5, the Chinese first observed the broom star. A white tail grew from 1° at discovery to over 15°. It gradually diminished in size and went out of sight after 34 days. Halley (1752) notes that the comet was observed from August 13 to 23 by Peter Apian at Ingolstadt.

A.D. 1607 (P = October 27.5, d = 0.24 on September 29).
When the comet was first discovered by the Chinese on September 21, its tail was pointing toward the southwest. On October 26, it was seen in the east. Johann Kepler, at Prague, made observations from September 26 to October 26, while Longomontanus, at Malmö, Sweden, and Copenhagen, Denmark, observed from October 1 to 26. (Halley, 1752). Thomas Harriot, who observed the comet from September 21 to October 23, left the most accurate position measurements recorded during this apparition (see Bessel, 1804).

A.D. 1682 (P = September 15.3, d = 0.42 on September 1).
According to Arago (1855), the comet was first seen by the Jesuits of Orléans, France on

the night of August 23 (N.S.), by Arthur Storer in the British colony of Maryland from August 24 through September 22; by Cassini, Picard, and La Hire in Paris, August 25–September 21; by Dörfel in Plauen, August 25–September 20; by Hevelius in Danzig, August 26–September 13, and by Flamsteed at Greenwich, August 30–September 19. Halley himself observed the comet that was to bear his name, from September 5 to 19 (August 26–September 9, O.S.).

A.D. 1759 (P = March 13.1, d = 0.12 on April 26).
The comet was discovered (and apparently anticipated) by a German amateur, Johann Georg Palitzsch, on December 25, 1758 and seen again by him on the two following nights. He communicated his findings to another amateur, Christian G. Hoffmann, chief commissioner of the excise in Dresden, who viewed the comet on December 28 and published a report in the *Dresdenische Gelehrte Anzeigen* no. 2 of 1759. He evidently did not realize that this was Halley's Comet. The identity of the object was made clear, however, in an anonymous pamphlet published in January 1759 in Leipzig, entitled *Anzeige dass der . . . von Halley . . . auf gegenwärtige Zeit vorherverkündigte Comet wirklich sichtbar sey*, which also presented a rather accurate ephemeris for the comet over the period January 28–May 13. The author of this pamphlet was apparently Gottfried Heinsius (Waff, 1985). Unaware of the German triumph, the French astronomer Charles Messier independently discovered the comet on January 21, 1759. Messier's observations, the most accurate of this apparition, extended until the beginning of June. The comet was widely observed throughout the world, and, according to Vsekhsvyatskii (1958), it was last recorded at Lisbon on June 22, 1759. An extensive series of physical observations is given by Delisle (1766) and Lalande (1765).

A.D. 1835 (P = November 16.4, d = 0.19 on October 13).
The comet was recovered on August 5, 1835, by Dumouchel at Rome. Important position measurements were made by F.W. Bessel at Königsberg, J.F. Encke at Berlin, W. Struve at Dorpat, K. Kreil at Milan, F.B.G. Nicolai at Mannheim, and Bouvard at Paris, as well as T. Maclear at the Cape of Good Hope. Carl (1864) provides a comprehensive listing of the published observations.

A.D. 1910 (P = April 20.2, d = 0.15 on May 20).
The comet was recovered by Max Wolf at Heidelberg on September 11, 1909. Prerecovery images were subsequently found on plates taken August 24 at Helwan, Egypt and September 9 at Greenwich. Röser (1984) also detected an image on a Heidelberg plate taken August 29, 1909. The comet was followed until June 16, 1911. Some of the voluminous physical observations were compiled by Bobrovnikoff (1931) and Perrine (1934).

II.2. *Observations Relating to the Physical Nature of Comet Halley.* Certainly by the seventh century, Chinese observers had concluded that comets derive their light from the sun and that, although comet tails directed toward the sun were occasionally observed, generally they pointed away from the sun (Needham *et al.*, 1957). Europeans rediscovered these findings some nine centuries later. The Chinese noted the anti-solar nature of Comet Halley's tail in A.D. 837, and they routinely connected morning and evening apparitions of the same comet – a point that still troubled Europeans in the 17th century.

In a classic irony, Kepler (1619) used his observations of Comet Halley in 1607 to demonstrate that cometary motion could be represented by a straight line. Although recognizing that his theory did not fit the comet's motion well, he felt that the extra work required to improve it was not warranted because comets do not return. He did note that comets shine by reflected sunlight and that solar rays draw out a portion of the material of the comet's head in an anti-solar direction, so that the tail represents the destruction of the head. To put these rather forward-thinking conclusions into perspective, however, we should also note that Kepler imagined that comets formed from impurities, or fatty globules in the ether, and that, once the comet was created, a special spirit or intelligence came into being to guide the comet – the spirit and the comet dissipating together at the end of the apparition. Kepler's views on the rectilinear paths of comets were widely held until Newton's work on the comet of 1680 (Newton, 1687).

Early in the nineteenth century, J.F. Encke investigated the motion of the comet that bears his name and found that, even after accounting for the solar and planetary accelerations, the comet's orbit and period appeared to be decreasing with time. Encke (1823) postulated that the comet's motion was affected by a resisting medium. During the 1835 apparition of Comet Halley, Bessel (1836a) observed the nuclear region carefully and saw emanations that had the appearance of a burning rocket, arising from the side of the nucleus that faced the Sun. Analogous to a rocket, such an emanation toward the Sun should produce a nearly radial thrust away from the Sun. Arguing that a resisting medium is not apparent in the motion of the planets, Bessel (1836b) suggested that comets are subject to a reactive force originating within themselves. Although Bessel's estimate of the action of this force upon Comet Halley was unrealistic, he anticipated the currently accepted explanation for these non-gravitational effects proposed by Whipple (1950).

On July 3, 1819, F. Arago (1820) directed his recently invented polariscope toward Comet 1819 II Tralles and determined that at least part of the light coming from the comet's tail was polarized and hence reflected sunlight. In October 1835, Arago also detected polarized light from Comet Halley (Arago, 1835).

II.3. *The 1910 Apparition of Comet Halley.* Although the data obtained at the time of Comet Halley's last apparition are mostly qualitative, much of the data can still be used to derive general properties for this comet. Visual brightness estimates have been compiled by Bortle and Morris (1984) in a light curve, showing the visual magnitude as a function of heliocentric distance. As already suggested by observations at earlier appearances, the comet appears to reach maximum intrinsic brightness about two weeks after perihelion. Linear tail lengths, as a function of heliocentric distance, were determined by Yeomans (1981) from naked-eye estimates of the comet's angular tail length. Although the actual tail extension observed depends upon the observing conditions and the instrument used, the visual tail length seems to reach a maximum about six weeks after perihelion.

During the 1909–1911 apparition, Comet Halley came rather close to the earth in May 1910 (0.15 A.U.) and was relatively bright. On May 19 the comet's ion tail swept past the earth but probably not the dust tail (Sekanina, 1981). An important contribution from the dust to the visible light is well established and, according to Donn (1977), Comet Halley seems to be a comet with a medium dust-to-gas ratio. Besides visual observations, numerous photographs and spectrograms were obtained at observatories all over the world.

The first spectrogram was taken on October 22, 1909, with the Lick Observatory's Crossley reflector. According to Newburn and Yeomans (1982), this 3-hour spectrogram showed a faint uniform continuum as its only prominent feature, but faint CN and C_2 were suspected, and the C_3 molecule at 4050 Å (then called C + H or Raffety bands) was present but weak. CN and (0-1) C_2 molecular bands were present in comparable strengths by early February 1910. Thereafter, the C_2 band was generally reported as being the stronger until late June, after which CN dominated. The (0-0) and (0-1) bands of CN, the C_3 bands, and the (2-0), (1-0), (0-0), and (0-1) bands of C_2 were observed in the head region, and perhaps the (0-2) band of CN and the (0-2) and (0-3) bands of C_2 as well. The CH molecular bands and the Na-D lines were also observed in the head. In the tail region, CO^+ was certainly present, and N_2^+ was observed on two nights. The spectral results of this apparition, summarized in the writings of Bobrovnikoff (1931, 1942), are consistent with typical spectral analyses of more recent bright comets. Hogg (1929) also gave an account of spectroscopic observations of Comet Halley and of other comets.

The successful recovery of Comet Halley on October 16, 1982 initiated a period of intense study that will include observations from the ground, from Earth orbit and from fly-by spacecraft. The knowledge gained from these studies will vastly improve our understanding of comets in general, and Comet Halley in particular – and require a considerable addition to the brief history presented here.

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