1979jrasc..73...24b

THE VISIBILITY OF HALLEY'S COMET

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(*Received July 28, 1978; revised November 29, 1978*)

ABSTRACT

When first seen on each return throughout its long recorded history, Halley's comet has had the same intrinsic brightness though the relative positions of the comet, earth and sun have made some apparitions more spectacular than others. The comet and the earth will be on opposite sides of the sun in February, 1986, making the circumstances of the next appearance the worst in over two thousand years.

Introduction. The visibility of any object depends on how bright it actually is and how near it is to the observer. The first section of this paper deals with the intrinsic brightness of Halley's comet and the second section with the effects of the geometrical configuration of earth, sun and comet on the comet's visibility.

The Brightness of Halley's Comet. Over eighty years ago, Holetschek (1896) carried out a comprehensive study of the brightness and tail lengths of ancient comets. He found that Halley's comet had practically the same intrinsic brightness when first discovered at each apparition. It may seem that there is no need to repeat his work since he had many of the same Oriental observations at his disposal as are now available in English translation in Ho's (1962) catalogue. But revisions have been made to some of the translations from the Chinese since then, and there have been great improvements in the computation of the past orbit of Halley's comet. In particular, Kiang (1971) analyzed ancient Chinese, Japanese and Korean observations and was able to use these to deduce many of the dates of the comet's perihelion passages back to 240 B.C. He also computed perturbations in the orbit at each return, adjusting the computed times of perihelion to agree with the observations whenever possible. Yeomans (1977) took a rather different approach in his investigation of the motion of Halley's comet. Using observations of the last five returns to calculate the non-gravitational forces, he incorporated these into his computation of the orbit back to 837 A.D. His computed times of perihelion agreed closely with those adopted by Kiang, and his more recent unpublished work has confirmed all of Kiang's dates of perihelion within five days.

Table I shows the positions of the comet, sun and moon (the latter with

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TABLE I

Positions of Halley's Comet

Return		Date				Comet		Sun		Moon	
No.	Year	Observed	*T*	log *r*	log *d*	R.A.	Dec.	R.A.	Dec.	R.A.	Dec.
−26	−11	Aug. 26[1]	−40.7a[2]	0.011	−0.297	68°.9[3]	27°.8	151°.9	11°.7	212°.6	−8°.5
		Oct. 20	15.1d	−0.172	0.209	214.7	−8.9	202.7	−9.6	218.0	−10.6
−25	66	Feb. 21	25.3a	−0.098	−0.024	283.3	−17.3	332.8	−11.3	56.5	17.4
−24	141	Mar. 27	6.8a	−0.221	−0.003	329.7	−2.7	4.5	2.0	19.7	4.8
−21	374	Mar. 4	15.8a	−0.172	0.007	306.1	−12.5	345.1	−6.4	21.6	12.5
−20	451	June 10	−14.7a	−0.181	−0.011	35.1	23.7	77.7	23.2	5.1	3.3
−19	530	Sept. 27	2.4d	−0.238	0.063	215.3	−5.7	185.5	−2.4	66.3	19.0
−16	760	May 16	−5.8a	−0.225	−0.022	18.9	19.1	56.5	20.0	16.3	10.0
−15	837	Mar. 22	22.3a	−0.122	−0.149	317.1	−9.6	4.8	2.1	139.2	14.3
−13	989	Aug. 12	−28.2a	−0.077	−0.218	87.7	36.2	146.1	13.7	224.1	−16.9
		Sept. 11	2.6d	−0.234	−0.003	208.1	−1.8	174.3	2.5	269.7	−20.2
−12	1066	Apr. 2	9.0a	−0.216	−0.026	340.2	0.6	16.1	6.9	62.8	16.7
		June 7	75.8d	0.195	0.213	149.1	4.3	80.9	23.3	218.6	−12.7
−11	1145	Apr. 28	5.8a	−0.230	−0.102	3.9	13.2	41.0	16.0	87.2	22.9
−10	1222	Sept. 3	−28.7a	−0.075	−0.438	123.2	42.8	167.8	5.3	109.9	26.3
		Oct. 23	22.1d	−0.126	0.237	223.2	−14.3	214.8	−14.0	53.6	21.1
−8	1378	Sept. 26	−44.2a	0.033	−0.544	92.2	43.4	189.7	−4.2	224.7	−19.7
		Nov. 10	1.6d	−0.239	0.148	254.9	−16.3	234.2	−19.4	123.2	16.5
−7	1456	May 27	−13.3a	−0.188	0.056	34.9	23.4	72.6	22.5	345.9	−3.6
		July 8	29.8d	−0.066	0.015	166.6	6.8	117.0	21.2	181.4	−1.9
−6	1531	Aug. 1	−24.6a	−0.105	−0.133	86.8	36.3	139.8	15.7	351.7	−2.6
		Sept. 8	13.8d	−0.184	0.097	205.5	−5.4	175.0	2.2	145.0	10.8
−5	1607	Sept. 16	−41.4a	0.015	−0.241	98.1	36.3	174.0	2.6	32.0	10.0
		Nov. 5	9.2d	−0.210	0.169	240.0	−15.3	220.5	−15.8	64.4	17.1
−4	1682	Aug. 24	−21.9a	−0.125	−0.271	112.1	41.8	153.5	11.0	40.9	10.5
		Sept. 22	7.7d	−0.217	0.044	212.8	−5.7	180.2	−0.1	71.5	17.5
−3	1759	Apr. 3	21.3a	−0.129	−0.086	327.4	−9.2	12.3	5.3	89.5	22.4
		May 27	75.7d	0.194	0.067	154.6	−4.4	64.2	21.4	85.7	22.3
−2	1835	Oct. 3	−44.3a	0.034	−0.365	103.2	41.5	188.4	−3.6	331.3	−17.2
	1836	Feb. 17	92.7d	0.258	0.132	219.9	−32.4	329.7	−12.3	336.1	−15.4
−1	1910	Apr. 16	−4.0a	−0.226	0.125	358.7	7.8	23.5	9.8	111.2	26.0
		June 13	54.8d	0.095	−0.011	157.8	−1.3	81.4	23.2	166.7	11.0

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[1] The Julian calendar is used for all returns except the most recent five.

[2] An 'a' denotes appearance, a 'd' denotes disappearance.

[3] All positions throughout this paper are referred to the equinox of date.

Supplementary Notes to Table I

Return-26 (-11, Aug.–Oct.). This is the earliest return for which there is a series of positions on definite dates. Kiang finds that the calculated path agrees with the first observation, August 26, and the last, 56 days later, but not all of the ones in between. The final position is only 12° from the sun.

Return-25 (66, Feb.–Mar.). There is some doubt as to which date should be chosen as the first appearance of the comet. Ho gives two separate accounts, [77] and [78]. (References to numbered entries in the Ho (1962) catalog are designated by [ ].) The first of these states only that a "guest star" was seen in the east on January 31, 66. If this really were an observation of Halley's comet, then it would have been less than 20° from the sun and the moon would have been just past full. The first date in Ho [78], February 20, seems more likely, especially since it is connected with a series of several positions.

Return -24 (141, Mar.–Apr.). Ho [100] states that a comet appeared in the east on March 27 pointing south-west towards the 13th lunar mansion. Calculation shows that the comet was in the 13th lunar mansion on March 27. The rest of the observations do agree with the ephemeris as shown by Kiang.

Return -21 (374, Mar.–May). The calculated position of March 4 is within the lunar mansion where the comet was said to have appeared on that date, if Ho's correction from the first to the second month is accepted.

Return -20 (451, June–Aug.). Ho [204] gives the date of appearance as May 17 but Kiang presents a good case for changing this to June 10.

Return -19 (530, Aug.–Sept.). August 29 is the first date mentioned in Ho [217] but Kiang notes that the positions of the comet recorded on that date and on September 1 are not compatible with the north-east motion which was also described. The comet's disappearance on September 27 seems much more definite.

Return -16 (760, May–July). The observed and calculated positions are in good agreement, including the precise first observation on May 16.

Return -15 (837, Mar.–Apr.). According to Ho [291], a comet appeared on March 22; Kiang's calculated position is within a degree of the observed place on that date.

Return -13 (989, Aug.–Sept.). The Chinese record that a comet appeared on August 12 (Ho [349]) and went out of sight after thirty days (Ho [350]) when the moon was just past first quarter. Kiang's calculated positions on these dates agree with the observations. The Japanese and Korean observations of July 6 and October 18, on the other hand, are not part of a connected series of observations and are rejected on that account.

Return -12 (1066, Apr.–June). A comet appeared on April 2 and went out of sight after a total of 67 days, i.e. on June 7. Kiang calculated the positions on both dates and found them to be consistent with the observations. However, he had to attribute some of the other observations to the comet's tail, and had to change the Japanese date by twenty days to bring about agreement.

If the comet really was seen on June 7, 76 days after perihelion, it must have been unusually bright, especially since the moon was approaching full. A post-perihelion brightening of at least two magnitudes must have occurred.

Return -11 (1145, Apr.–June). The earliest Chinese observation of April 26 indicates only that a comet was seen in the east – too vague to be absolutely certain of identity with Halley's comet. The Japanese records, however, provide a series of positions extending from April 28 to May 17 which do agree with the calculated ephemeris.

Return -10 (1222, Sept.–Oct.). The earliest date, September 3, is the first in a short series of Korean observations, while the latest date, October 23, concludes a series of Chinese observations. The calculated ephemeris only reproduces some of the observations, and the calculated position on October 23 is just 8°.4 from the sun.

Return -8 (1378, Sept.–Nov.). The appearance and disappearance dates and positions seem certain, although there are no other dated observations given in Ho [475].

Return -7 (1456, May–July). The comet was seen from May 27 to July 6 in China and until July 8 by Paolo Toscanelli in Italy (Celoria 1885).

Return -6 (1531, Aug.). According to Pingré (1783) the comet was seen from August 1 in Europe, whereas in China, Ho records that it was visible from August 5 and went out of sight after 34 days.

Notice that at this and the next two apparitions, the comet was first seen in bright moonlight.

Return -5 (1607, Sept.–Oct.). Lubieniecki (1667) gives September 16 as the first date of visibility in Europe. Wendelin observed the comet until November 5 (Hind 1852). Kiang notes that in China the comet was seen from September 21 to October 12.

Return -4 (1682, Aug.–Sept.). Surprisingly, the earliest and latest reported dates of visibility of the comet at this apparition seem both to appear in a letter to Newton from Arthur Storer of Maryland (Turnbull 1960).

Return -3 (1759, Apr.–May). This was the first predicted return. Messier saw the comet with great difficulty with his naked eye on April 1 (Mascart 1910), but he had been following it for some months with a telescope. It seems inconsistent to compare this observation with the first naked-eye sighting at other apparitions, but even if it were adopted, the (log r, log d) point would be in line with the others. Instead, a popular article in *Gentleman's Magazine* (1759b) has been used. It states, "The Comet, which has been so long expected, was seen the first time that we know of at New York in America, on the 3d of April, in the morning. It then rose about three o'clock and was, as near as could be judg'd by the eye (for want of instruments) somewhere in the sign Pisces; its tail about 12 or 13 degrees of the circle in length, and of a silver colour." A letter in the same magazine (1759a) suggests that May 27 was the last date of visibility, though on the previous night it was described as having "a luminous appearance very evident to the naked eye (notwithstanding the light of the moon) yet rather dim than splendid" (*London Magazine* 1759).

Return -2 (1835, Sept.–1836, Feb.). Though naked-eye observations began on September 23, it was at least a week later that the comet became conspicuous. Quetelet (1835) described it as fifth magnitude on September 29–30. Captain Smyth (1836) wrote that on September 25, "the comet was now visible to the naked eye but not readily", but on October 2 he found "the comet was readily seen by the unassisted eye". Littrow (1835) wrote that "it was perfectly visible to the naked eye as a star of third magnitude" on the morning of October 3 at Vienna. At Yale, Loomis (1836) found the comet "distinctly visible to the naked eye" on September 25, and "as bright as a star of the fourth magnitude" on October 3. The final date, February 17, occurs in Maclear's (1838) account: "The comet becomes fainter but is still visible to the naked eye".

Return -1 (1910, Apr. – June). Wolf's observation with the unaided eye on February 11 is remarkably early (Crommelin 1910). Barnard (1914) wrote, "As seen from Yerkes it was visible to the naked eye from April 29 to June 11, but poor weather and forest fires prevented observations for several days prior to the 29th". The comet had been seen with the naked eye in South Africa on April 16 (Weir 1927) and Ernst (1911) gave the magnitude as 2.9 on that date. While June 11 was the last date on which the comet was seen without instruments at Yerkes, it was seen until June 13 in Brazil (de Seixas Tinoco 1910).

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errors perhaps as large as two degrees) for a selection of dates, generally the first and last date on which the comet was visible to the naked eye at each apparition. Kiang's orbital elements were used for the comet, and linear interpolation in tables by Tuckerman (1962, 1964) provided the co-ordinates for the sun and moon, except that for the last four returns, direct calculations of these co-ordinates had to be carried out using formulae in the *Explanatory Supplement to the Astronomical Ephemeris* (1961). The value of T, shown in column 4 of the table, is the number of days after perihelion, and the variables r and d whose logarithms are shown in columns 5 and 6 are the computed distances (in AU) of the comet from the sun and earth, respectively. The observations themselves have not been included here since they are mostly from Ho's catalogue and Kiang has discussed many of them. In fact Kiang computed many of the same ephemerides as are shown in Table I.

In figures 1 and 2, the values of log d are plotted versus log r for the various appearances and disappearances on the dates adopted in Table I. Several uncertain observations had to be completely excluded; unless an observation was part of a connected series in general agreement with the calculated path, it was not used. More detailed explanations are included in the notes accompanying Table I.

The reason for plotting log d versus log r is that the apparent brightness, I, of a comet is usually assumed to be given by a formula of the form $I = I_0 r^{-k} d^{-2}$, or (in magnitude units) $m - M = 2.5\, k \log r + 5 \log d$, where I_0 and M are the absolute brightness and magnitude at the standard distance $r = d = 1$ AU. The exponent k is generally between 2 and 6. For an object like an asteroid, having no self-luminosity, $k = 2$. In the absence of any better information, a comet's apparent magnitude is often calculated on the assumption that $k = 4$. Allen (1973) gives $k = 4.2 \pm 1.5$ and warns that k is not necessarily constant for any comet.

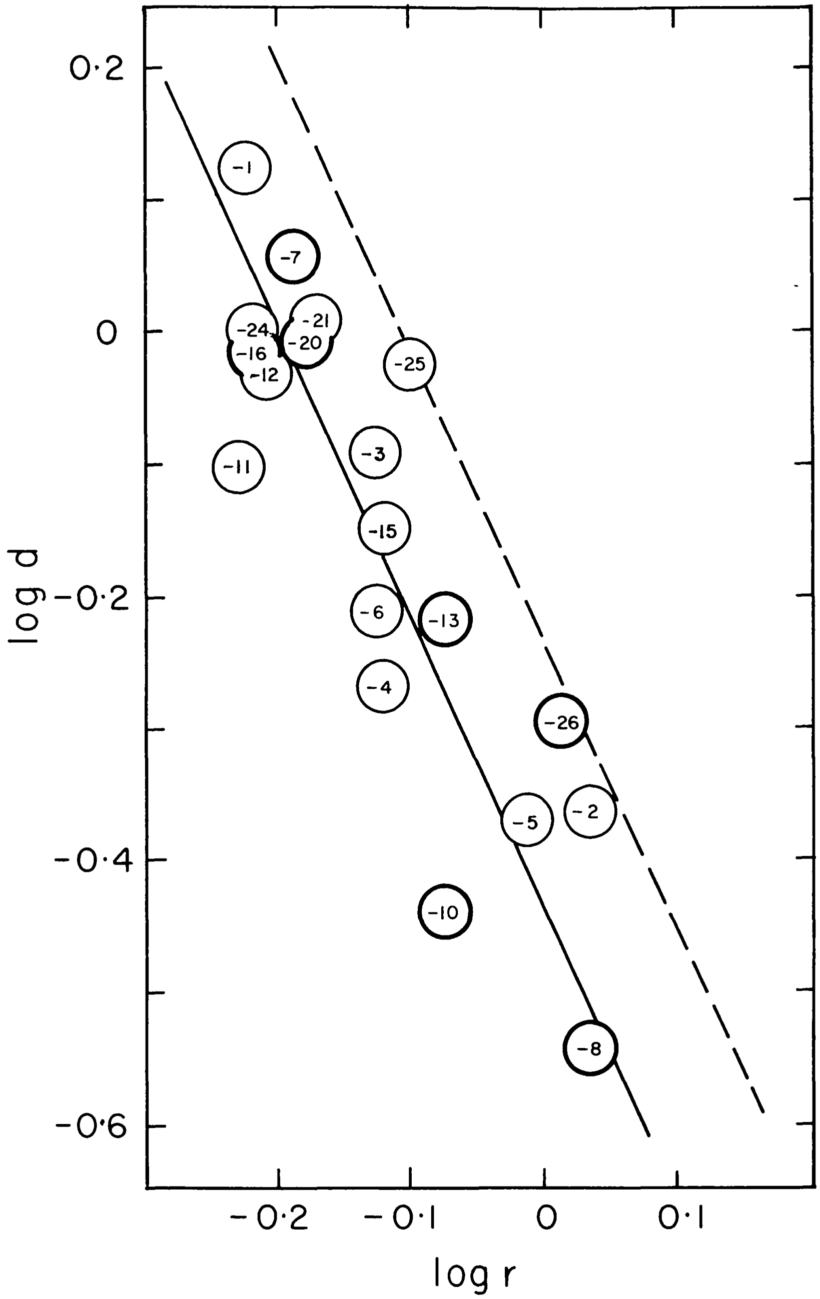

FIG. 1—A log-log plot of the distances of Halley's comet from the earth (d) and from the sun (r) at discovery, for several well-observed apparitions. The return numbers are enclosed by the circles. The solid straight line, fitted to return numbers −7, −8, −10, −13, −16, −20 and −26, has the equation $11.5 \log r + 5 \log d = -2.2$, and the dashed line, one magnitude fainter, has the equation $11.5 \log r + 5 \log d = -1.2$.

It is to be expected that Halley's comet would have had roughly the same apparent magnitude when it was first seen at each return. Probably the comet would not have been noticed until it brightened considerably above the limit of naked-eye visibility, but it probably would have been seen

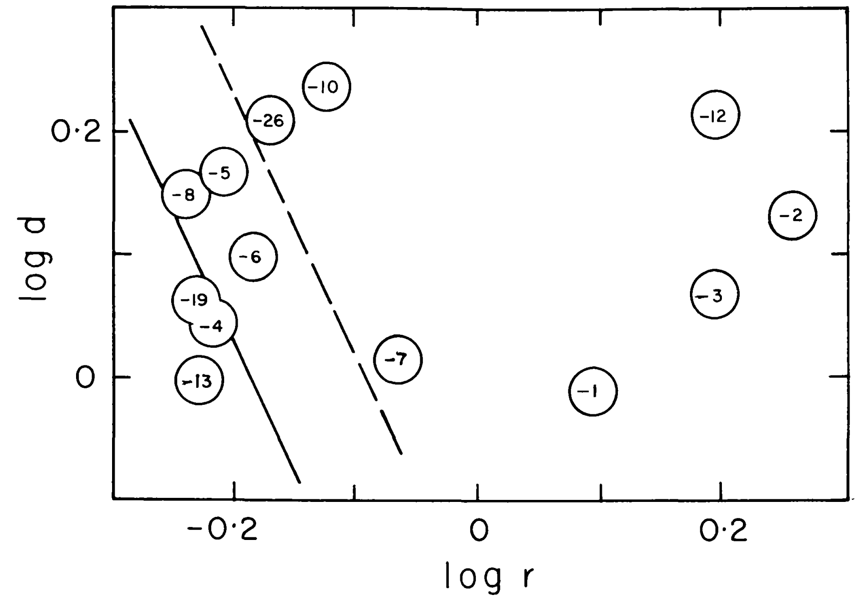

FIG. 2—The values of log r and log d when Halley's comet was last seen at several well-observed apparitions. The lines are the same as in figure 1.

before it became a great deal brighter. A visual magnitude of 3 or 4 might seem like a reasonable estimate, and this will be confirmed shortly. If the comet also had the same absolute magnitude at each return, then $2.5\,k \log r + 5 \log d$ would be a constant for all apparitions and a plot of log d versus log r for all apparitions should show the points in a straight line with a slope of $-k/2$.

Figure 1 shows how constant $m - M$, and presumably M itself, has been for Halley's comet over many returns – surprisingly constant since it is generally felt that a comet fades as it ages. The points appear to conform well enough to a straight line to justify fitting a linear relationship, but there may be some question as to whether all the points should be used. After all, some of the observations were made against a bright sky background when the comet was seen close to the sun, or when moonlight was strong; some of these first-sightings were before and some after perihelion, and there might have been an asymmetry in the pre- and post-perihelion intrinsic brightness of Halley's comet, as indeed there was in 1910; and finally, though the adopted dates for the most recent three returns correspond to times when the comet became readily visible to the naked eye, there could be some bias introduced by including them, since the comet's position was well known in advance. It was decided to make the sample as homogeneous as possible, and to make a least-squares fit only to the pre-perihelion first-sightings when the comet was at least 30° from the sun, when the moon was no fuller than quarter phase (if it was above the horizon when the comet was), and to use only observations prior to the first predicted return in 1759. For the seven points satisfying all these criteria (indicated by the heavy circles in figure 1), the equation resulting from the least-squares fit (represented by the solid straight line in figures 1 and 2) is

$$11.5 \log r + 5 \log d = -2.2.$$

The good agreement of the line in figure 1 even with the points corresponding to the most recent apparitions allows the line to be calibrated in terms of magnitudes. There are two independent estimates of the comet's magnitude for the plotted point of October 3, 1835. The average of these estimates, which are given in the supplementary notes to Table I, is 3.5. For the 1910 return, there is a relation derived by Ernst (1911),

$$m = 5.8 + 13.5 \log r + 5 \log d,$$

for observations before perihelion. He derived this, and the relation for observations after perihelion,

$$m = 4.0 + 13.5 \log r + 5 \log d,$$

from 400 estimates and measures of the brightness of the comet at its most recent apparition, but he found that these formulae were not valid when r was less than 0.8, i.e. when $\log r < -0.1$, where most of our points lie. Nonetheless, the pre-perihelion formula can be made to fit the right-hand end of the line in figure 1 if m is assumed to be 3.5. The equation of the line then becomes

$$m = 5.7 + 11.5 \log r + 5 \log d.$$

While Ernst's formulae indicate that the comet was 1.8 magnitudes brighter after perihelion than before for $r > 0.8$, the historical post-perihelion points plotted in figure 1 show no tendency to be brighter than the pre-perihelion ones. However, all these post-perihelion observations were made just after the comet emerged from close proximity to the sun, and for all of them $r \leq 0.8$.

Figure 2 shows the disappearance values of $\log d$ and $\log r$. They are too scattered to provide any quantitative results. Note, however, that they tend to lie above and to the right of the line of figure 1. This is natural since a comet, once discovered, would likely be followed until it moved further from the sun and earth than when it was first seen. The fact that the comet was occasionally followed with the naked eye out to large values of r and d suggests that sometimes, certainly in 1066, Halley's comet was considerably brighter a few *weeks* after perihelion than the pre-perihelion formula would have predicted, though it was no brighter a few *days* after perihelion. This delayed brightening was very evident in 1910, Yeomans (1977b).

The Holetschek Effect and Halley's Comet. The visibility of long-period comets is influenced by important selection effects. When Everhart (1967) studied the discovery positions of 337 unexpected comets of period greater than 200 years, he concluded that 69% of the retrograde comets were actually found in the morning sky and that 81% of the retrograde comets could have been discovered first in the morning sky. He also confirmed an effect first pointed out by Holetschek (1891), namely that comets which arrive at perihelion when the earth is on the other side of the sun are not as likely to be discovered.

Although telescopic comets were the subject of Everhart's paper, naked-eye observations of Halley's comet at its many returns in the past display the same characteristics. Comet Halley has nearly always appeared first in the morning sky. The other phenomenon, known as the Holetschek effect, can be quantified by using a parameter j, equal to the heliocentric longitude of the earth at the time of the comet's perihelion minus the longitude of the comet's perihelion. In order to see how this effect related to Halley's comet, Kiang's orbital elements for 295 A.D. were used to construct an ephemeris covering the interval from 80 days before to 80 days after perihelion. The date of perihelion was then increased by ten days and a new ephemeris computed. This process was repeated 36 times so that a complete range of values of j from 0° to 360° was covered.

Figure 3 is based on these ephemerides and shows the $\log r$ versus $\log d$ tracks for various values of j. The symmetrical feature of the diagram, whereby the track for some value of j is the same as the track in the reverse direction for $360° - j$, arises because the argument of perihelion, ω, is almost 90° (actually $94^\circ\!.8$).

There was no very significant reason why the orbital elements for 295 A.D. were chosen, and the whole process was completed again for 1222 A.D. in case the change in the elements over the intervening millennium might have produced a different result. In fact, there was hardly any difference except for slightly less symmetry, ω now being $103^\circ\!.6$.

Figure 3 shows that if Halley's comet had ever had $j = 180°$, its track would never have crossed the line corresponding to the dashed line in figure 1, except when it approached very close to the sun. That is, the comet would always have been fainter than it was when first seen at any of its recorded apparitions. Even if j had only been close to 180°, say 160° or 200°, the comet would never have appeared bright enough to reach the solid line of figure 1, and could have very easily been missed. But strangely, up until now, Halley's comet has assiduously avoided coming to perihelion when the earth was on the opposite side of the sun. The actual values of j and their distribution is shown in Table II and figure 4, the data again being

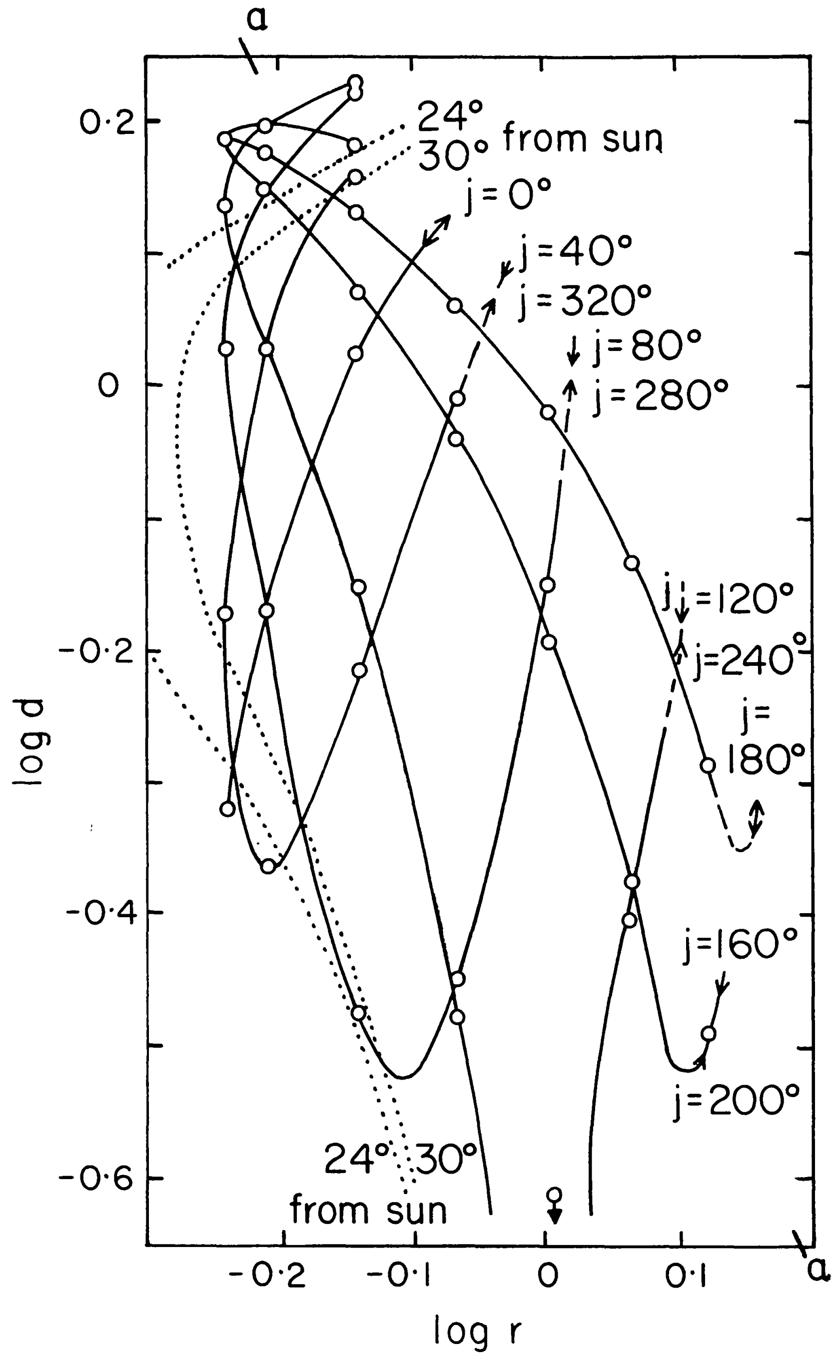

FIG. 3—Tracks of Halley's comet on a log d versus log r plot, for several values of j. Also shown are dotted lines indicating points which are 24° and 30° from the sun. A straight line joining $a - a$ corresponds to the dashed line in figures 1 and 2.

derived from Kiang's orbital elements and Tuckerman's tables. There are no values of j in the 90° interval between 118°.5 and 208°.8. The probability of that happening by chance alone is $(\frac{3}{4})^{29} = 0.00024$.

TABLE II

VALUES OF *j* FOR HALLEY'S COMET

Return No.	Year	Longitude Earth (*a*)	Longitude Comet's Perihelion (*b*)	*j* (*a-b*)	Return No.	Year	Longitude Earth (*a*)	Longitude Comet's Perihelion (*b*)	*j* (*a-b*)
—29	—239	185°.6	271°.8	273°.8	—14	912	291°.4	289°.3	2°.1
—28	—163	9.0	273.0	96.0	—13	989	351.3	290.6	60.7
—27	—86	306.2	275.1	31.1	—12	1066	188.7	291.6	257.1
—26	—11	10.2	275.4	94.8	—11	1145	217.9	292.9	285.0
—25	66	125.4	276.6	208.8	—10	1222	15.0	294.0	81.0
—24	141	178.2	277.6	260.6	—9	1301	38.0	295.3	102.7
—23	218	234.9	278.9	316.0	—8	1378	54.9	296.4	118.5
—22	295	209.4	280.0	289.4	—7	1456	266.7	297.8	328.9
—21	374	148.2	281.2	227.0	—6	1531	341.1	298.8	42.3
—20	451	272.7	282.4	350.3	—5	1607	43.8	300.0	103.8
—19	530	3.6	283.7	79.9	—4	1682	352.7	301.0	51.7
—18	607	174.4	284.8	249.6	—3	1759	172.2	302.3	229.9
—17	684	8.5	286.0	82.5	—2	1835	53.4	303.6	109.8
—16	760	244.4	287.0	317.4	—1	1910	209.2	304.6	264.6
—15	837	205.0	288.2	276.8					

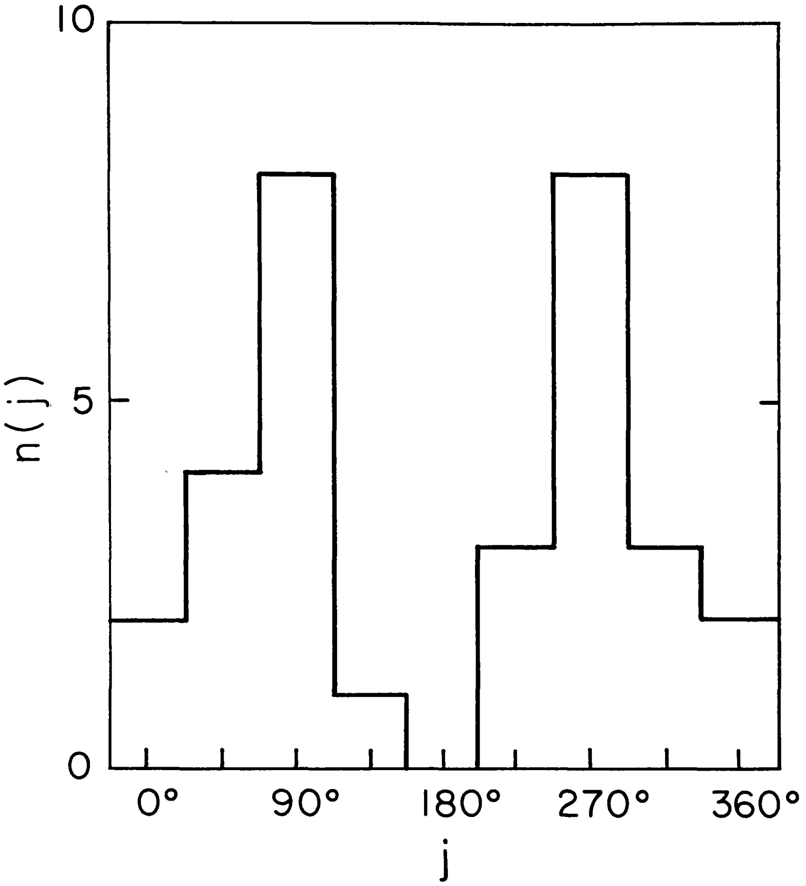

FIG. 4—A histogram showing the distribution of values of *j* for the last 29 returns of Halley's comet, using Kiang's times of perihelion.

Unfortunately for earth-bound observers, when Halley's comet comes to perihelion seven years from now, *j* will equal 164°.7. Never in its many visits has Halley's comet been seen under less favourable conditions. Had this happened centuries ago, the ancient Chinese would likely not have even noticed the comet. But we at least have the advantage of knowing where to look, and providing there are still some dark sites in 1986, we might be lucky enough to see this famous old bearded traveller even without a telescope.

Acknowledgement. I am indebted to D. K. Yeomans of the Jet Propulsion Laboratory, Pasadena, California, for his generous, constructive and helpful suggestions which made the publication of this paper possible.

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