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The sunward spike of Halley's comet

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Summary. On wide-field photographs from late April till early June 1986, comet Halley is seen to display a spike-like extension in the general direction of the Sun, projecting to distances of about 700,000 km from the nucleus. The spike was composed of dust and its enormous sunward extent (compared to other dust features) suggests an anomalously high ratio of particle ejection velocity to solar radiation pressure. The grains are either dielectric or slightly absorbing, $\ll 0.1$ µm in size, and undetected optically from Earth except when it is located in or very near a plane of their concentration. The only plane to which these grains ejected from Halley's wobbling nucleus can possibly be confined for long is the plane normal to the comet's angular momentum vector. This concept is applied to interpret the spike observations.

Key words: comet Halley – comet dust – sunward spike – rotation – light scattering

1. Introduction

Reports of the photographic detection, in late April and early May 1986, of a spike extending from comet Halley's head to within 20° of the direction to the Sun were entirely unexpected. The feature had nothing in common with the antitail that had been photographed extensively two months earlier. The interesting aspects of the spike include its projected length – up to some 700,000 km or more (almost ten times the distance typically reached by dust features on the sunward side of the nucleus) – and its appearance shortly after A'Hearn et al. (1986a) had observed prominent cyano jets and within two weeks of the predicted time of the Earth's transit across what was called Halley's equatorial plane (Sekanina and Larson, 1986).

2. Observations

We have collected a total of 34 photographic observations that show the spike, with a varying degree of clarity, from 1986 April 28 till June 7 (Table 1). Unfortunately, the distribution of the observations in time is less than satisfactory, with a wide gap between 12 May and 1 June.

As a rule, the spike is more pronounced on the panchromatic 2415 emulsion than on the blue sensitive IIa-O. This is regarded as evidence that the spike's light is continuous and that it therefore is made of dust. The fact that the IIa-O emulsion is much more grainy than 2415 must also contribute to the difference.

3. Image processing and positional reduction

Because of the spike's low surface brightness, reliable measurement of its direction and length requires computer processing. The digitization, image enhancement, and positional reduction have now been completed for 27 observations. The best results have been achieved with a technique based on double linear-shift differencing in the direction perpendicular to the spike. This approach permitted measurement of points along the spike that indicates a precision to $\pm 2°$ in position angle. Each photograph has been oriented with the aid of several SAO field stars. The length of the spike is determined with lesser precision.

Nine examples of the digitally processed images are displayed in Fig. 1. The spike points to the west-northwest of the nucleus. The long trail to the east-southeast is a streamer in the dust tail, which makes an angle of 10–15° with the somewhat wavy ion tail to the north of it (Sect. 5). The positional data on both the spike and the streamer determined from the 27 photographs are listed in Table 2. Columns 1–4 and 6–7 are self-explanatory. The reader is referred to Sects. 4 and 5 for remarks on the contents of the other columns.

4. Results and interpretation

The spike's position angle was changing very slowly, if at all, during the 40-day period of observation, even though the Sun-Halley vector rotated by 24°, from 89° on April 28 to 113° on June 7. The spike's projected length of $\sim$700,000 km implies characteristic flight times of two weeks or more for dust particles ejected at initial velocities of 0.5–0.7 km s^{-1}. A simple fountain model gives a crude upper limit of $\beta \simeq 0.1$–0.2 the solar attraction for the particle accelerations by solar radiation pressure. Based on theoretical calculations of the scattering efficiency for radiation pressure, the particles must be extremely small ($\ll 0.1$ µm in size) and dielectric or slightly absorbing, in order to satisfy the constraints imposed on both the ejection velocity and the repulsive

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Table 1. List of photographic observations

Mid-exposure 1986 (UT)		Instr.[a]	Emulsion	Exp. (min)	Observer
April	28.204	122	IIIa-J[b]	15	Helin
	29.189	122	IIa-O[b]	15	Helin
	29.225	122	IIIa-J[b]	45	Helin
	30.180	P46	IIa-D	5	Helin
	30.194	P46	IIa-D	10	Helin
	30.201	B30	2415	20	Emerson
	30.301	122	IIIa-J[b]	14	Helin
May	1.165	B30	2415	32	Emerson
	1.185	B30	IIa-O	10	Emerson
	2.238	P46	IIa-D	3	Helin
	2.256	P46	IIa-D	8	Helin
	3.093	V20	2415	8	Schmidt
	3.139	V20	2415	10	Schmidt
	3.147	V20	2415	7	Schmidt
	4.094	V14	2415	25	Chester
	4.116	V20	2415	15	Schmidt
	4.124	V14	2415	30	Chester
May	4.130	V20	2415	15	Schmidt
	4.145	V14	2415	25	Chester
	4.147	V20	2415	7	Schmidt
	4.168	V14	2415	20	Chester
	4.198	B30	2415	30	Emerson
	10.185	B30	IIa-O	8	Emerson
	11.089	V14	2415	25	Chester
	11.113	V14	2415	25	Chester
	12.082	V20	2415	25	Schmidt
	12.100	V20	2415	10	Schmidt
	12.115	V20	2415	15	Schmidt
June	1.184	B30	2415	30	Emerson
	4.105	V14	2415	30	Chester
	4.120	V14	2415	30	Chester
	6.194	122	IIa-O[b]	20	Helin
	6.198	P46	4415	8	Helin
	7.208	122	IIa-D[b]	20	Helin

[a] Instrument abbreviations:
122 = 122-cm f/2.5 Schmidt, Palomar Mountain Observatory
P46 = 46-cm f/2 Schmidt, Palomar Mountain Observatory
B30 = 30-cm f/1.8 Schmidt, Barnard Observatory
V20 = 20-cm f/1.5 Schmidt, near Paris, VA
V14 = 14-cm f/3.6 Schmidt/Newtonian, near Rixeyville, VA

[b] With a GG385 filter.

force. These grains scatter essentially according to the Rayleigh law and their optical detection is exceedingly difficult, except possibly at very high optical depths.

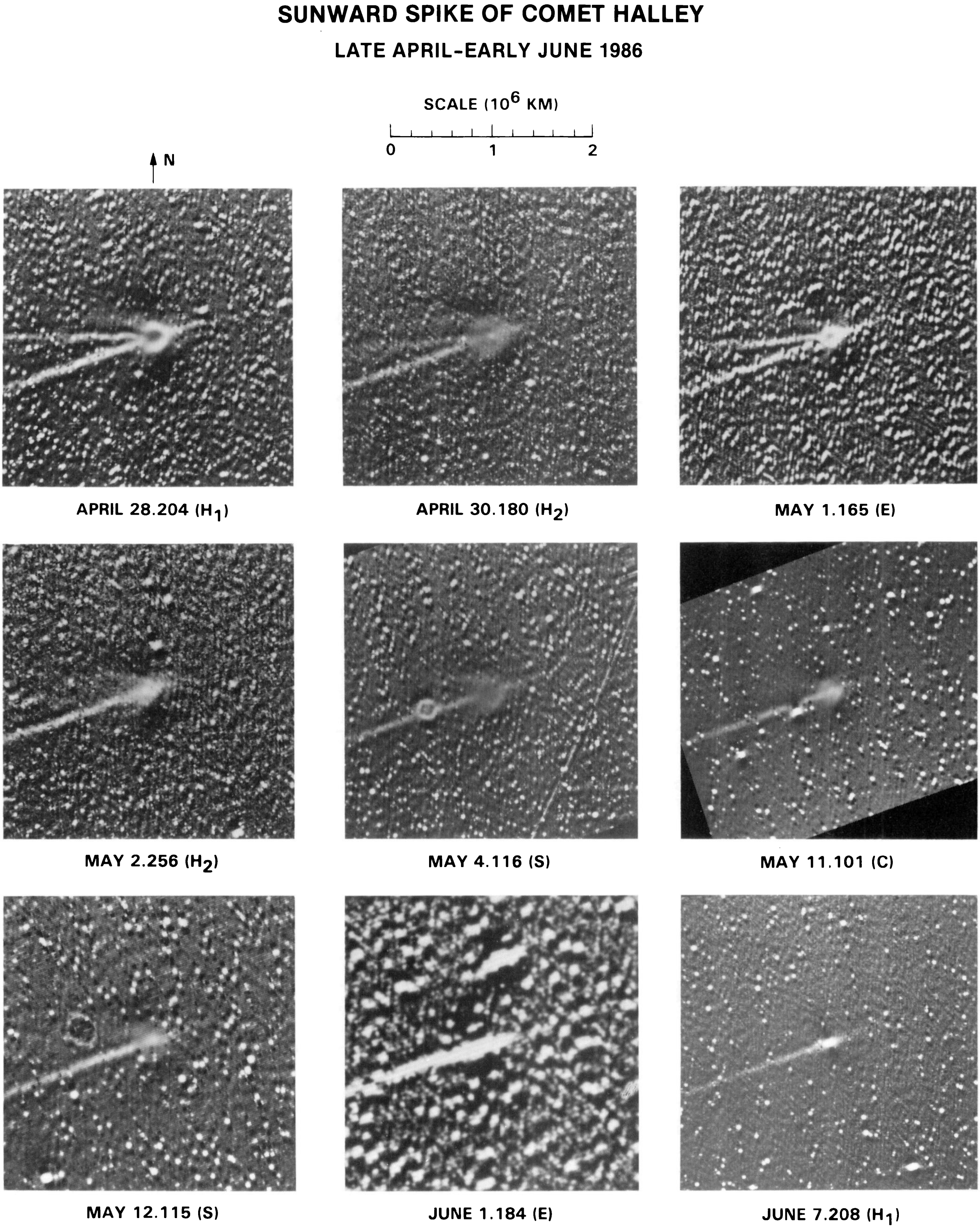
The existence of inefficiently scattering, subfemtogram grains in the comet's atmosphere is documented by the various dust experiments on the Halley missions; their obvious presence about the time of the spike's detection is inferred from prominent cyano and C_2 jets invisible in continuum bandpasses (A'Hearn et al., 1986a, b).

The appearance of the sunward spike is suggestive of a thin sheet of dust observed edge-on and is indeed reminiscent of an antitail during the Earth's transit across a comet's orbital plane. However, the situation is different in the sense that the time scale is shorter and, primarily, because it is the ejection velocity (much higher than that of the antitail particles) and not the radiation pressure that determines the ejecta's motions. If the subfemtogram grains are found to be concentrated in a particular plane, it is so because they were expelled from the comet that way. For a rotating nucleus, continuous emissions from discrete vents could remain confined to a plane for an appreciable period of time only if the sources are located in or near an invariable plane and ejecta are released parallel to it. If Halley's nucleus were in pure rotation, this plane would coincide with the equatorial plane. Since this apparently is not so (Sekanina, 1986a, 1987), the invariable plane is normal to the comet's angular momentum vector, about which the spin axis must freely precess, unless of course outgassing exerts torques on the nucleus. Reasonable estimates of these torques suggest that Halley's angular momentum vector is likely to be essentially constant on time scales of at least a few weeks. To determine the position of the angular momentum vector, we have compared the measured position angles of the spike with the time-history models for the projected invariable plane. This plane does not project in the sky as a straight line except at the time of transit and we have assumed that, in general, the spike's direction is perpendicular to the plane of maximum projection foreshortening. We have then optimized the position of the angular momentum vector to achieve the best fit to the observations. The residuals of the solution are presented in column 5 of Table 2. The mean residual is $\pm 1\overset{\circ}{.}9$, which is comparable to the error of measurement (Sect. 3). If defined, similarly to the rotation-pole position (Sekanina, 1981), by two Eulerian parameters, the angular momentum vector is determined by the "obliquity" $I_0 = 12°$ and by the "argument" $\Phi_0 = 300°$, corresponding to right ascension 17° and declination −63° (equinox 1950.0). These coordinates are almost identical with those established previously for what was termed the "rotation pole" (Sekanina, 1986b; Sekanina et al., 1986).

5. Discussion and conclusions

Our measurements are in excellent agreement with those made recently by M. Jäger on his unprocessed images of Halley obtained on five nights between 1986 May 3 and 25 (Fischer, 1987, private communication). He employed his 20-cm f/1.5 Schmidt camera, using the 2415 emulsion. He finds the spike's position angle to be constant at 287° during the 22-day interval and its projected length between 570,000 and 840,000 km.

Although it is our intention to continue collecting more information on Halley's sunward spike, the presented photo-



APRIL 28.204 (H_1)

APRIL 30.180 (H_2)

MAY 1.165 (E)

MAY 2.256 (H_2)

MAY 4.116 (S)

MAY 11.101 (C)

MAY 12.115 (S)

JUNE 1.184 (E)

JUNE 7.208 (H_1)

Fig. 1. Examples of digitally processed photographs that show the sunward spike of comet Halley. The prints have a common scale and are oriented with the north up and the east to the left. The times are the mid-exposures in UT and the parenthesized letters identify the observers: C = G. Chester; E = G. Emerson; H_1, H_2 = E.F. Helin, using, respectively, the 122-cm and 46-cm telescopes; and S = R.E. Schmidt

Table 2. Positional measurements of the spike and streamer

Time of mid-exposure 1986 (UT)		Sunward spike				Streamer			Position angle of streamer, minus position angle of spike, plus 180°
		Length		Position angle			Position angle		
		apparent (arcmin)	projected (10^6 km)	obs. ^{a} (deg)	o-c (deg)	Apparent length (deg)	obs. (deg)	o-c (deg)	(deg)
April	28.204	16.0	0.50	283.7	+0.5	2.9	108.7	0.0	+5.0
	29.225	23.5	0.77	281.0	-2.6	4.2	109.7	+0.8	+8.7
	30.180	12.6	0.43	282.6	-1.5	5.3	108.0	-0.9	+5.4
	30.201	19.2	0.65	283.8	-0.3	>1.6	107.9	-1.0	+4.1
	30.301	19.5	0.66	283.3	-0.8	2.8	109.0	+0.1	+5.7
May	1.165	14.8	0.52	(285.)	(+0.7)	>1.2	109.5	+0.5	(+4.5)
	2.238	12.8	0.47	287.4	+2.7	4.7	109.1	0.0	+1.7
	3.093	13.5	0.51	287.5	+2.6	>3.0	108.8	-0.3	+1.3
	3.139	11.1	0.42	285.7	+0.8	>3.0	108.4	-0.7	+2.7
	3.147	17.5	0.66	284.8	-0.1	>3.0	109.4	+0.3	+4.6
	4.094	6.7	0.26	(286.)	(+0.8)	2.6	108.9	-0.2	(+2.9)
	4.116	15.1	0.59	287.4	+2.2	4.4	109.4	+0.3	+2.0
	4.124	<16.3	<0.64	287.9	+2.7	2.6	109.3	+0.2	+1.4
	4.130	13.3	0.52	287.6	+2.4	4.6	109.0	-0.1	+1.4
	4.145	8.4	0.33	283.7	-1.5	>2.1	108.6	-0.5	+4.9
	4.147	15.0	0.59	285.8	+0.6	4.2	109.4	+0.3	+3.6
	4.168	6.8	0.27	288.9	+3.7	>2.1	109.2	+0.1	+0.3
	4.198	13.0	0.51	287.4	+2.2	>1.8	109.1	0.0	+1.7
	10.185	10.7	0.51	286.2	-0.2	>1.4	108.7	-0.2	+2.5
	11.101 ^{b}	9.3	0.45	290.4	+3.9	>1.8	109.3	+0.5	-1.1
	12.082	11.1	0.55	288.4	+1.7	4.4	108.8	0.0	+0.4
	12.100	12.9	0.64	290.1	+3.4	4.4	108.7	-0.1	-1.4
	12.115	14.5	0.73	288.6	+1.9	4.4	108.6	-0.2	0.0
June	1.184	4.9	0.39	287.3	-0.4	>1.3	107.8	-0.2	+0.5
	4.112 ^{b}	3.9	0.32	(287.)	(-0.7)	>1.4	108.1	+0.2	(+1.1)
	6.194	10.1	0.87	287.4	-0.3	2.8	108.2	+0.3	+0.8
	7.208	5.3	0.46	285.9	-1.8	2.6	108.2	+0.3	+2.3

^{a} Uncertain data are parenthesized.

^{b} Measurement from two consecutive, digitally co-added images (mid-exposure times in Table 1).

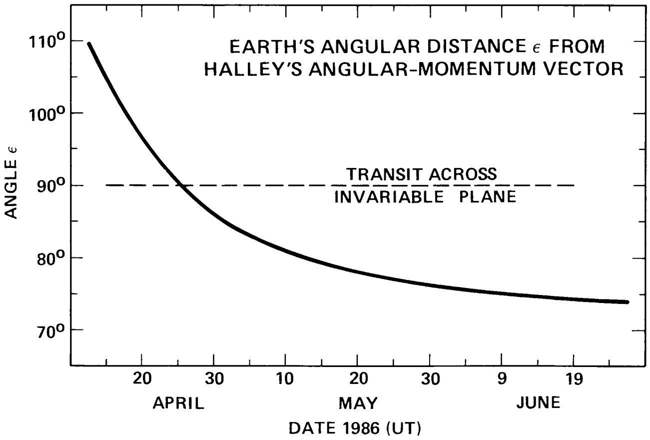


Fig. 2. Angle that the direction to Earth subtends with Halley's angular momentum vector, calculated for the latter's coordinates: right ascension 17°, declination −63°. The comet's invariable plane was crossed by Earth on 25 April 1986. Note that Earth was moving almost parallel to the plane in June

graphic evidence is already sufficient to conclude that the feature pointed in essentially the same direction for at least 40 days, apparently concentrating in the plane normal to the comet's angular momentum vector. If Halley's nucleus does indeed wobble, as it now appears to be the case, the position of the angular momentum vector is not expected to coincide on the Giotto images with the normal to the long, almost straight limb on the night side of the nucleus, which Keller et al. (1986) identified with the presumed "spin axis".

The comparative persistence of the spike until June is understood from Fig. 2, in which the Earth's angular distance from the comet's angular momentum vector is plotted as a function of time. While this angle was changing rapidly in late April, it leveled off during June, when Earth was staying within 16° of Halley's invariable plane. This qualitatively explains why the spike showed up rather suddenly but was fading very gradually. Figure 2 also suggests that the spike could have been detected on photographs taken as early as mid-April. Unfortunately, the moon began to interfere about that time.

Also examined was a possible relationship between the spike and the long streamer that appeared totally straight and pointed in the direction opposite to that of the spike. The last column of

Table 2 shows that the angle the streamer made with the spike varied with time and was not exactly 180°, implying the absence of any obvious relationship between the two phenomena. On the other hand, the streamer's position angles can be fitted with a mean residual of $\pm 0\overset{\circ}{.}4$ on the assumption that the feature represented a signature of an outburst of dust that took place some 27 ± 7 days before perihelion or within a week of 1986 January 13. The large uncertainty in the time of ejection is due to the well-known "pileup" effect that drastically limits the time resolution of old dust emissions. The maximum measured lengths of the streamer (Table 2) suggest, rather consistently, peak radiation-pressure accelerations between 0.02 and 0.026 the solar attraction, implying the presence of submillimeter-sized and larger particles. On a number of photographs the streamer can be followed all the way to the edge. The position-angle residuals for the individual observations are listed in column 8 of Table 2. No attempt has as yet been made to verify the outburst on photographs taken before the end to April, but attention is called to Lamy's (1986) identification of a dust event centered 13 days before perihelion and extending over some 12 days and to Gérard et al.'s (1986) detection of two OH flare-ups on 9 and 16 January 1986.

Potential effects of electrodynamic forces on the spike particles have not been investigated. Although such forces are believed by some to be significant for grains whose dimensions are smaller than $\sim 0.1\ \mu$m, this was shown by Finson and Probstein (1968) to depend on the particles' typical separation distance with respect to the Debye length. Besides, the forces acting on charged grains are strongly particle-size dependent and should cause them to disperse in space. A major component of these forces is expected to be in the direction normal to the orbital plane (Horanyi and Mendis, 1985), an effect not observed with the spike.

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