FOURTH INTERNATIONAL WORKSHOP ON COMETARY ASTRONOMY

The fourth International Workshop on Cometary Astronomy (IWCA IV) was originally scheduled to be held in Japan near the time of the long total solar eclipse of 2009 July 22, in the hopes of drawing international participants travelling to view the eclipse. Unfortunately, there was very little interest expressed by potential attendees from outside Japan, apparently because the path of totality does not cross the large Japanese islands. When the meeting in Japan was cancelled, the *ICQ* approached cometary astronomers in China (with the path of totality crossing the southern part of the large eastern city of Shanghai) about the possibility of holding the IWCA IV in Shanghai, and the response has been good — both in that the Chinese Astronomical Society and the Beijing Planetarium have agreed to co-host the IWCA IV with the *ICQ* in Shanghai and that numerous international cometary observers have indicated already that they will plan to attend the one-day meeting on the day after the eclipse (*i.e.*, on Thursday, 2009 July 23). After some discussion with the Chinese astronomers, it has been decided that both Chinese and non-Chinese astronomers will meet together for half the day, with that portion of the meeting conducted in English; the other half-day will see the Chinese attendees conducting their meeting in Chinese, with the non-Chinese attendees continuing their discussions in English in another room. Additional details will be posted at the *ICQ* website as they become known.

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On a Forgotten 1836 Explosion from Halley's Comet, Reminiscent of 17P/Holmes' Outbursts

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Abstract. *Although it is often affirmed that the outbursts displayed by comet 17P/Holmes, including the megaburst of 2007, have never been observed in any other comet, I find that about ten weeks after its 1835 perihelion, comet 1P/Halley experienced a similarly massive explosion in late January 1836, at 1.44 AU from the sun, with a peak intrinsic magnitude of at least +0.3, midway between the limits on the outbursts of 17P/Holmes. Predictably, this outburst of Halley's comet accompanied the formation of a disk-shaped, sharply-bounded dust halo, which was steadily expanding at a rate of 0.575 km/s into a feature of nearly-parabolic outlines, very similar in appearance to the halos of 17P/Holmes in 1892-1893 and 2007. The 1836 episode of Halley's comet and its aftermath thus compare favorably with the 17P/Holmes events in all respects.*

1. Introduction

There is a general understanding that the enormous explosions, or outbursts, that accompanied episodes of a rapidly expanding, sharply-bounded dust halo of comet 17P/Holmes in 1892-1893 and again in October 2007 have never been observed in any other comet. While the 2007 megaburst still remains unrivaled as the most powerful event of this kind on record, the uniqueness of 17P/Holmes is a myth. As demonstrated in this paper, another member of this peculiar group of objects is — of all comets — 1P/Halley!

The explosive events of comet 17P/Holmes, examined in a recent paper (Sekanina 2008 — hereafter referred to as Paper 1), begin with the appearance of a starlike, rapidly brightening nuclear condensation that is soon to be recognized as a sharply-bounded disk, expanding steadily at an essentially constant rate. Reaching its peak at the end of the event's active phase, the light curve begins to display a slowly declining post-event plateau. In the meantime, the growing disk-shaped condensation evolves into a halo, with its boundary on the antisolar side gradually becoming more diffuse and elongated. The halo's surface brightness progressively diminishes with time until the feature eventually disappears, completing the last phase of outburst development.

This paper uses the same terminology for outbursts and their properties as Paper 1. In particular, the brightness — corrected for personal and instrumental bias and referred to a geocentric distance Δ of 1 AU by a Δ^{-2} law — is described by a normalized magnitude H_Δ. A normalized magnitude referred to a heliocentric distance r of 1 AU by an r^{-2} law is called an intrinsic magnitude H_0. The normalized and intrinsic magnitudes at maximum light, which occurs shortly after the explosion begins, are called, respectively, the peak normalized magnitude $(H_\Delta)_{\rm peak}$ and the peak intrinsic magnitude $(H_0)_{\rm peak}$. The event's early phase is described by the self-explanatory onset time $t_{\rm onset}$, identical with the time when the halo begins to expand; by the rise time $\Delta t_{\rm rise}$, which is the time interval between the onset time and the time of peak brightness $t_{\rm peak}$; and by the amplitude $\Delta H_{\rm peak}$, which is the difference between the magnitudes at the onset and at maximum brightness. The rate of expansion of the dust halo is described by a (projected) expansion velocity $v_{\rm exp}$.

For the three events of comet 17P/Holmes, the nominal range of the critical parameters was found to be as follows (Paper 1): onset time between 143 and 216 days after perihelion; rise time between 1.8 and 6 days; amplitude between 4 and 14 magnitudes; peak intrinsic magnitude between +1.9 and −0.5 (before phase-angle corrections); mass of 10^{13}-10^{14} g of dust injected into the atmosphere; and expansion velocity between 0.28 and 0.50 km/s. The 1892-1893 outbursts were found to be less powerful than the megaburst of 2007 in terms of both the peak intrinsic brightness (by 1.7 to 2.4 magnitudes) and the expansion velocity (by 0.12 to 0.22 km/s). It was shown in Paper 1 that the explosions of 17P/Holmes differ significantly from all other outbursts, including the very powerful flare-ups of comet 29P/Schwassmann-Wachmann, in that they must originate from emission sources of a fairly large extent on the nucleus and, from the very beginning, are features of nearly global proportions on the scale of the nucleus. It is proposed that any emission episode during which the mass of dust suddenly injected into the atmosphere amounts to 10^{13} g or more — and the comet begins to display the characteristic, rapidly expanding halo whose shape gradually changes from a sharply-bounded disk to a catenary-like and/or parabolic feature — be called a super-massive explosion or explosive event. The expanding cloud's peak intrinsic magnitude $(H_0)_{\rm peak} \leq 2$ mag (before a correction for the phase effect) can serve as a fair proxy constraint. The rest of this paper is focused on providing evidence that Halley's comet experienced a super-massive explosion in 1836.

2. The Forgotten Explosion of Comet 1P/Halley in 1836

While showing continually-changing jet morphology in the coma during the apparitions of 1835, 1910, and 1986 (e.g., Bessel 1836, Bobrovnikoff 1931, Rahe *et al.* 1969, Larson *et al.* 1987), Halley's comet was not reported to undergo a major outburst in 1910 (e.g., Bobrovnikoff 1941a, 1941b; Morris and Green 1982; Bortle and Morris 1984; Marcus 1986) or 1986 (e.g., Green and Morris 1987), until a flare-up more than 5 mag in amplitude was observed 5 years past perihelion, in February 1991, at 14.3 AU from the sun (West *et al.* 1991).

At the 1835-1836 apparition, the comet was first detected by Dumouchel (1836) on 1835 August 5 UT and observed extensively at various sites through its perihelion point (1835 November 16.44 UT) until late November, when it was less than 20° from the sun. After solar conjunction, which occurred on December 5, the comet was first detected in Milan (Kreil 1837) and New Haven (Loomis 1836, 1848) on December 31 UT, about 32° from the sun, and by January 22 it was also observed at Padua (Santini 1836), Geneva (Müller 1842), Munich (Lamont 1837), Mannheim (Nicolai 1836), Cambridge (Airy 1847), and elsewhere. The comet during this period of time was poorly placed for observation, relatively faint, and not a naked-eye object (see section 4 of this paper).

John Herschel, who between 1834 and 1838 was conducting his southern-sky observations with a powerful 46-cm $f/13$ reflector and a 13-cm $f/17$ equatorial from Feldhausen (an old estate at Wynberg, a suburb of Cape of Good Hope, located on the southeastern side of the Table Mountain), saw the comet for the first time on 1835 October 28 UT, when he compared its naked-eye brightness to that of a third-magnitude star (Herschel 1847). He continued to observe the comet until November 10 UT, when, in strong twilight, he estimated its brightness at magnitude 2-3 or 3. After the conjunction, Herschel unsuccessfully searched for Halley's comet on the mornings of December 22 and 26, but had no more search opportunities before he received word from Thomas Maclear, of the Cape Observatory, who detected the tailless comet on the morning of January 25 (Maclear 1838). There is an ambiguity about the brightness: on page 92 of his report, Maclear noted that to the naked eye the comet was as bright as a star of magnitude 2-3 or 3, while in a log on page 114 he remarked that the comet was "to the naked eye equal to a star of 2 magnitude".[1] Herschel (1847) found the comet the next morning "as a bright star of the 4th, or small one of the 3rd magnitude", which to the naked eye "offered the aspect of a star"; in the night-glass "its appearance was that of a highly condensed globular nebula"; in the equatorial it looked like "a bright, round, and a very nearly uniform nebulous disc", more sharply defined on its eastern, sunward side; and in the reflector, the comet was "a most singular and remarkable object", a total change compared to its aspect at the time of pre-perihelion observations.

Continuing his remarks on the comet's appearance in the eyepiece of the large reflector, Herschel (1847) commented on "the extraordinary sharpness of termination of the head, a phenomenon ... quite unique in the history of comets". He noticed "a vividly luminous nucleus, or rather ... a miniature comet having a nucleus, head and tail of its own" and pointed out that the whole (i.e., including the disk-shaped feature) "was encircled with a strong *coma* [Herschel's emphasis], which nearly filled the field of view (15′ diameter)." [2]

A strong similarity with the appearance of 17P/Holmes during and after its 2007 megaburst is fairly obvious from this description alone. The confirmation of the two comets exhibiting the same kind of phenomenon is provided by observational details secured by both Herschel (1847) and Maclear (1838). During the very first night of his observing, Herschel became confounded when finding, with the equatorial, that his two measurements of the disk-like head's sharply-defined breadth taken $2^{\rm h}14^{\rm m}$ apart differed by nearly 15″, implying that *"the comet was actually increasing in dimensions*

[1] A nominal magnitude of 2.5 has been adopted for Maclear's observation on Jan. 25 UT in this paper.

[2] To avoid confusion, a few words about the used terminology. The term "coma", as employed by Herschel, refers to the extent of (presumably gas) emissions in the atmosphere observed both before and after the unusual developments began after Jan. 23. For example, Müller (1842) reported a coma 2′-3′ in diameter on Jan. 15, and 4′ in diameter on Jan. 21 UT. The diameter of nearly 15′ mentioned by Herschel in the morning of Jan. 26 was likely to be a combined effect of an increased size of the physical coma and of a greater power of his telescope — compared to instruments used by other observers. This is generally in line with the result by Maclear, who, observing with the 34-cm $f/12$ reflector of the Cape Observatory on the morning of Jan. 25, recorded a "total" coma diameter of 8′.2, while the disk of expanding dust was less than 3′ in diameter. The relationship between the coma and the disk (or halo) of Halley's comet was similar to that for 17P/Holmes in late 2007 (cf. Figure 2 in Paper 1). In Herschel's terminology, the disk evolved into an expanding envelope. This term is rather unfortunate, because the envelope was actually smaller than the coma until the latter's disappearance.

with such rapidity that it might ... be seen to grow!" [Herschel's emphasis]. Only after convincing himself that his determinations were not in error, did he believe this result. The conclusions that the phenomena in 1P/Halley and 17P/Holmes are of the same nature and refer to a rapidly expanding dust halo are further strengthened by sets of drawings that accompany both Herschel's treatise and Maclear's account. To illustrate this evidence, I present digitally processed renditions of four of Herschel's drawings of the dust halo, from 1836 January 26-29 UT, in Figure 1. They are compared with four images of comet 17P/Holmes taken by Peter Vasey of England during November 2007 in Figure 2 to show how impressive the correspondence really is!

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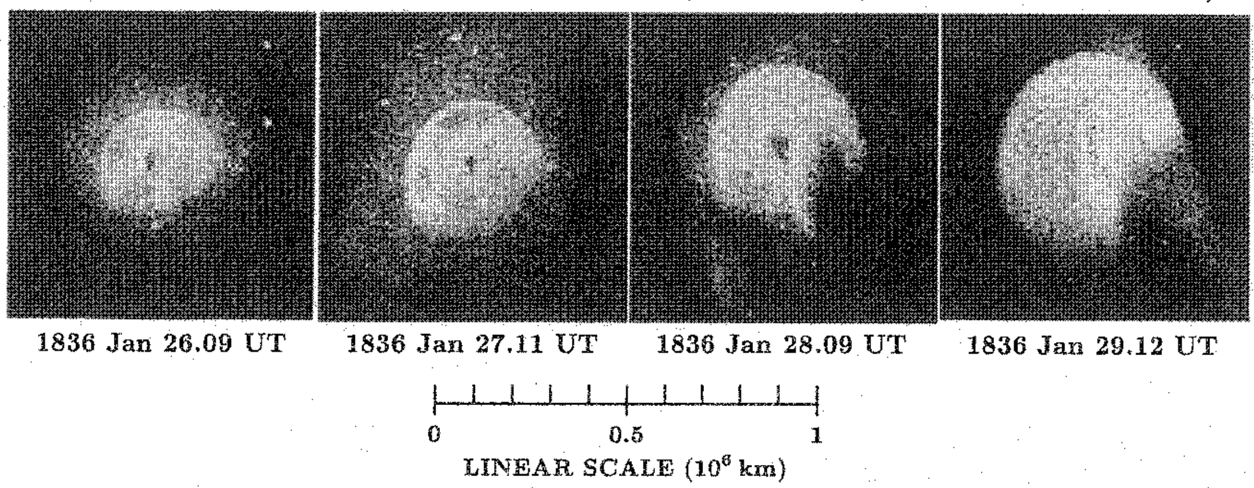
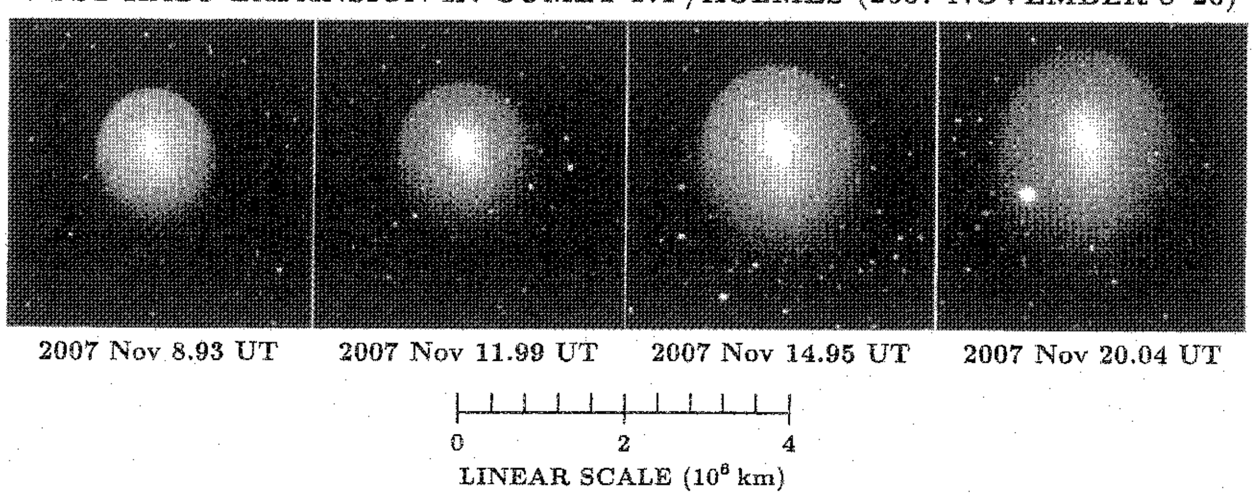
DUST HALO EXPANSION IN COMET 1P/HALLEY (1836 JANUARY 26–29)



Above: Figure 1. Steady expansion of the sharply-bounded dust halo of comet 1P/Halley between 1836 January 26 and 29, following the comet's outburst that began on January 23. Noted is a striking similarity with the appearance of comet 17P/Holmes in Figure 2, even though the linear scales are different. The frames are digitally processed drawings made by J. F. W. Herschel, showing the comet as it appeared to him in the eyepiece of his 46-cm f/13 reflector at Feldhausen, Cape of Good Hope, South Africa. The images were taken, respectively, 2.82, 3.84, 4.82, and 5.85 days after the onset of halo expansion. The nuclear condensation appearing darker than the surrounding halo is an artifact of the image inversion process applied. East is up, and south is to the left. The sun is in a direction slightly south of east. (From Herschel 1847.)

Below: Figure 2. Steady expansion of the sharply-bounded dust halo of comet 17P/Holmes between 2007 Nov. 8 and 20, following the comet's megaburst that began on Oct. 23. Noted is a striking similarity with the appearance of comet 1P/Halley in Figure 1, even though the linear scales are different. In the first frame on the left, the diameter of the halo is about equal to the diameter of the sun. The images — referring to the times of, respectively, 16.2, 19.3, 22.3, and 27.3 days after the onset of halo expansion — were taken by P. Vasey, Plover Hill Observatory, Hexham, Northumberland, U.K. He used his Canon 350D camera with a William Optics ZS66 6.6-cm f/5.9 refractor and a reducer that brought the focal length down from 39 cm to about 30 cm. North is up, and east is to the left. The direction to the sun rotates from the north-northeast in the first frame to very slightly west of the north in the last frame. (Reproduced by permission.)

DUST HALO EXPANSION IN COMET 17P/HOLMES (2007 NOVEMBER 8–20)



3. 1P/Halley's Expanding Dust Halo

It is most fortunate that 1P/Halley's dust halo began to expand just shortly before Maclear detected the comet for the first time after its conjunction with the sun and that Herschel immediately recognized the significance of the observed physical changes and made, with his powerful telescope, a lasting contribution toward learning the nature of this phenomenon.

Herschel's (1847) treatise provides not only a bulk of information on the halo, but also describes attempts at analyzing his own observations, the applied technique showing his intuitive mind. Noticing that the rate of expansion of the rapidly growing halo (which he referred to as an envelope) was "nearly uniform during the whole interval embraced by [the] observations", he extrapolated the trend back in time to arrive "at the singular conclusion that on [January 21.52 UT] the envelope *had no magnitude* [Herschel's emphasis], that in short, at that moment, a most important physical change commenced in the comet's state. Previous to that instant, it must have consisted of a mere nucleus, a stellar point, more or less bright, and a coma more or less dense and extensive. At that instant, the formation of the envelope commenced, and continued in the manner and at the rate above described."

If Herschel went one step further and converted the angular dimensions into linear dimensions, his "mean rate of dilatation" of $21''$ per diem would have yielded a projected expansion velocity of $\sim$ 0.3 km/s, a value that by modern standards is distinctly more typical for microscopic dust ejecta from comets than Bessel's (1836) ejection velocity of 1.1 km/s that was derived from the extent of the head of Halley's comet in the sunward direction. Herschel's considerations of an expanding halo were based on his measurements of a vertex distance, that is, the distance from the nuclear condensation to the halo's sunward end. The vertex distance was generally smaller than the halo's half-breadth, yielding a somewhat lower expansion velocity. In addition, Herschel did not fit his data points with a straight line, a circumstance that affected his determination of the time of "the physical change in the comet's state", that is, the onset time of expansion.

Herschel's effort to determine this onset time also happens to illustrate the role of personal contacts among 19th-century astronomers. An intriguing section of his 1847 treatise describes a debate that developed between him and Palm H. L. von Boguslawski, Director of the Breslau Observatory. On the occasion of a visit to H. Wilhelm M. Olbers in July 1838, Herschel got acquainted with a letter from Boguslawski to Olbers that mentioned Boguslawski's observation of Halley's comet in the morning of January 23 at Breslau.[3] In response to his request for more information, Herschel received, in September 1838, a letter in which Boguslawski stated that on that date he had "actually observed the comet *as a star* [Herschel's emphasis] of the 6th magnitude, a bright, concentrated point, which showed no disc with a magnifying power of 140," adding that the object was at the comet's predicted position and, because of its day-to-day motion, it could not be a field star. Boguslawski further reported to Herschel that he was inspecting the comet for about 27 minutes around January 23.196 UT and that he derived January 22.90 UT for the time when the expansion had begun, that is, about 33 hours later than Herschel originally found. [The local mean times have been converted to UT by the author of this paper.] Herschel concurred with Boguslawski's arguments that this later time better fitted Herschel's own measurements of the vertex distance.

There are several circumstances about this observation by Boguslawski that are unusual. One, I am aware of no report in the literature by Boguslawski himself on this subject; if Herschel did not mention it in his treatise, this information would have been lost. No one else observed the comet on January 23 and 24 UT, the nearest previous observations having come from January 22 (Lamont 1837). Two, the brightness reported by Boguslawski on Jan. 23 (magnitude 6) suggests that the comet was more than 3 magnitudes fainter than two days later, when observed by Maclear (1838); this indicates that, like with 17P/Holmes, the halo formation was accompanied by an outburst. Three, Boguslawski's onset time of expansion, nearly 0.3 day before his observation on January 23, appears to be incorrect for two reasons: (i) as he himself admitted in the letter to Herschel, the halo should have been, at the time of his Breslau observation, $19''$ in diameter, while the object was seen to be starlike and definitely less than $3''.5$ in diameter, and (ii) as the light increase is the steepest at the very beginning of the outburst, the comet's brightness should have already been strongly elevated, at least a halfway to the level reported by Maclear on January 25 UT, if the event were in progress; an examination of the light curve in Sec. 4 suggests that it was not. And four, it strikes one as strange that after Boguslawski conclusively satisfied himself, 24 hours later, that the "star" indeed was the comet, he did not consider it important enough to record any follow-up information on the comet's appearance and/or brightness in the morning of January 24; all he was focused on was the comet's motion. If he provided additional physical information from that morning, a more complete history of the event would be available.

Having an occasion to read the remarks by Loomis (1848), of which I had until recently been unaware, I noticed that he felt baffled by the circumstances of Boguslawski's observation as well. Loomis first described his and D. Olmsted's telescopic observations of Halley's comet in the mornings of January 14-16, when it appeared in moonlight as an object of ragged outlines and a few arcminutes across.[4] Loomis then pointedly asked how could these observations be reconciled with Boguslawski's a week later, bringing up the question of whether it was possible that "Boguslawski mistook a *fixed star* [Loomis' emphasis] for the comet?" In this context, Loomis noted that the comet "must have been difficult to observe in Breslau, being only $10°$ above the horizon when on the meridian, and the comet did not come upon the meridian until about *sunrise*" [Loomis' emphasis]. He also pointed out that Boguslawski "does not state that he found the comet at

[3] Herschel was aware of the possibility of an inadvertent error in the date of Boguslawski's observation. In particular, Herschel noted that an erroneous date in a British Astronomical Association's Report for 1838-1839 was subsequently corrected.

[4] As mentioned in Sec. 2, Müller (1842) reported the comet to have a coma $4'$ in diameter only 48 hours before Boguslawski's controversial observation.

all" in the morning of January 24, adding that the used "language might be construed as implying that he did not." Loomis then carried his argument to its logical conclusion: "If such were the case, would not this circumstance afford a presumption that he [Boguslawski] had mistaken his object the preceding night? — for it is difficult to suppose that the comet had vanished entirely ..."[5] Since none of the observers who saw the comet between December 31 and January 22 reported it to be a naked-eye object, the case of a mistaken identity for the object observed by Boguslawski on January 23 implies that Halley's comet was that morning probably fainter than magnitude 6.

As is apparent from the results of Herschel's and Maclear's observations and their implications (Sec. 5), the halo's nearly-circular outlines were short-lived, acquiring soon catenary-like and later quasi-parabolic boundaries. Under these circumstances and also because of the phase-angle range involved (Sec. 5), it is questionable whether the vertex distance, used by Herschel and Boguslawski, is the most appropriate parameter to measure an expansion rate. Revisiting this issue, I prefer instead to employ the breadth of the halo, in part also because Maclear (1838) measured this dimension more often than the vertex distance, so that more data by Herschel and by Maclear could be combined into one set.

Maclear's (1838) first halo measurement, from the morning of January 25 UT, does not fit the expansion curve based mostly on Herschel's measurements. Maclear described the comet's appearance in the 34-cm $f/12$ reflector, the largest instrument at his disposal, as "an opaque, circular, planetary disc", whose diameter was 131″. He did not give an exact time, but from his astrometric observations it should have been about January 25.10 UT. Maclear did not record the feature's diameter the next morning, so that direct comparison with Herschel's results is not possible. However, C. Piazzi Smyth, an assistant at the Cape Observatory, made, under Maclear's guidance, careful drawings on these two days of the disk's circular appearance, from which it follows that the diameter on the 25th was 0.59 the diameter on the 26th. Judging from his astrometry on the 26th, Maclear observed the comet at almost exactly the time of Herschel's second measurement of the breadth, 252″, so that the diameter on the 25th comes out to be $0.59 \times 252'' = 149''$, fully 18″ greater than measured by Maclear and more in line with Herschel's measurements.

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Table 1. Breadth of the dust halo following the outburst of comet 1P/Halley in January 1836.

Date 1836 (UT)	Reported halo's breadth: apparent (arcsec)	Reported halo's breadth: linear (10^3 km)	Residual $O-C$ (10^3 km)	Observer
Jan 25.104	149[a]	173	−9	Maclear
26.042	237.3[b]	274	−1	Herschel
26.135	252.0	291	+6	Herschel
27.049	328.9[b]	378	+3	Herschel
27.051	333.5	383	+7	Herschel
28.060	422.2[b]	481	+5	Herschel
29.064	497.2[b]	563	−13	Herschel
31.134	702	783	+2	Maclear
Feb 2.067	823.3[b]	906	(−67)	Herschel
2.101	988	1086	(+109)	Maclear
3.076	835.3	912	(−162)	Herschel
3.077	939.2[b]	1025	(−49)	Herschel
5.074	937.7	1008	(−264)	Herschel
6.119	1334.2	1423	(+47)	Maclear
13.059	2088	2114	(+48)	Maclear
19.018	2448	2376	(−282)	Maclear

[a] Corrected by calibrating the halo diameter on Piazzi Smyth's drawings from Jan 25 and 26 with Herschel's breadth measurement on Jan 26.
[b] Measured along the meridian.

[5] One may pursue this controversy a step further by asking "which star may have Boguslawski observed"? The comet's calculated position for 1836 Jan. 23.196 UT is $\alpha = 15^{h}58^{m}.4$, $\delta = -29°05'$ (equinox 2000.0). The nearest bright star was ρ Scorpii, 22′ to the west-southwest and of apparent visual magnitude 3.9. The next star brighter than magnitude 8-9 was nearly 37′ away and of magnitude 7.3, an unlikely candidate. Even though there is no magnitude 6 star at the comet's position calculated for the critical time, Loomis' hypothesis may still be plausible, if Boguslawski confused star fields and underestimated (near the horizon) the brightness of ρ Sco by ~ 2 mag, both distinct possibilities. It turns out that a mix-up by Boguslawski is strongly supported by a surprising finding that < 24 hours later, when the object was supposed to be gone, the comet was in fact passing by ρ Sco to within 1′!

Table 1 compiles the available halo-breadth measurements, with corresponding linear dimensions, and presents the residuals from a fit of a uniformly expanding cloud to the data points between January 25 and 31. As the halo grew in size and became progressively fainter, the measurements were increasingly less accurate and the residuals much too large. Table 2, which compares the parameters of 1P/Halley's 1836 explosion with those for the 2007 megaburst of 17P/Holmes (Paper 1), shows that the expansion velocities were very similar, 0.575 km/s for 1P versus 0.50 km/s for 17P, even though 1P was only 1.44 AU from the sun, fully 1 AU closer than 17P.

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Table 2. Comparison of the explosion of comet 1P/Halley in 1836 and the megaburst of comet 17P/Holmes in 2007.

Source of data	Event's parameter	Comet 1P/Halley	Comet 17P/Holmes[a]
Expanding halo	Date of event's onset, $t_{\rm onset}$ (UT)	1836 Jan 23.27 ± 0.07	2007 Oct 23.7 ± 0.2
	Time after perihelion, $t_{\rm onset} - T$ (days)	67.83 ± 0.07	172.2 ± 0.2
	Heliocentric distance, $r_{\rm onset}$ (AU)	1.443 ± 0.001	2.435 ± 0.001
	Initial expansion velocity, $v_{\rm exp}$ (km/s)	0.575 ± 0.009	0.50 ± 0.02
Light curve	Peak intrinsic magnitude, $(H_0)_{\rm peak}$ (mag)	+0.3 ± 0.5[b,c,d]	−0.53 ± 0.12[c,e]
	Amplitude, $\Delta H_{\rm peak}$ (mag)	>3.5	14 ± 0.5[b]
	Rise time, $\Delta t_{\rm rise}$ (days)	2–5	1.8 ± 0.4[b]
	Post-event plateau	very likely	persistent
	Dust injected into coma during event[f]:		
	Total cross-sectional area, $X_{\rm dust}$ (km^2)	5×10^7	8×10^7
	Total mass, $\mathcal{M}_{\rm dust}$ (g)	0.6×10^{14}	1.0×10^{14}

[a] From Sekanina (2008).
[b] Estimated mean error.
[c] Not corrected for phase effect.
[d] Estimating from Divine *et al.* (1986) a magnitude correction of -0.7 ± 0.3 for phase angle of 37°, a corrected peak intrinsic magnitude is $(H_0)_{\rm peak}({\rm corr}) = -0.4 \pm 0.6$.
[e] Estimating from Divine *et al.* (1986) a magnitude correction of -0.4 ± 0.2 for phase angle of 17°, a corrected peak intrinsic magnitude is $(H_0)_{\rm peak}({\rm corr}) = -0.9 \pm 0.2$.
[f] With phase factor Φ estimated from Divine *et al.* (1986) at 0.53 for 1P and 0.68 for 17P, and taking particle geometric albedo, particle bulk density, and particle mass distribution function from Sekanina (2008).

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The 1836 halo expansion curve of Halley's comet is compared in Figure 3 with the expansion curves of 17P/Holmes (from Paper 1) following its 2007 megaburst and the 1892 and 1893 events. It is noted that by late February, the breadth of Halley's halo was about twice the diameter of the sun. Herschel (1847) remarked that all trace of the halo's outline disappeared in his reflector by March 18, some 4 months after perihelion, when the comet was 2.23 AU from the sun and the halo was expected to reach 5.5 million km across.

My result for the onset time of expansion, 1836 January 23.27 ± 0.07 UT (Table 2), has implications for Boguslawski's controversial January 23 observation. The beginning and end of the 27-minute interval during which he stated he was inspecting the comet are at Jan. 23.187 and 23.206, respectively — suggesting that, even if he observed the comet, he may have missed the event. At a 1-σ level, the halo would have begun to expand just before his observing terminated; a pre-event observation would be consistent with the fact that Boguslawski mentioned no brightening to Herschel. By contrast, expectation is that the comet should have been much harder to miss (even low above the horizon) in the morning of January 24 when the event was unquestionably in progress.

4. The Light Curve

As far as I am aware, Loomis (1836) was the first person who noticed that Halley's comet was during the 1835-1836 apparition intrinsically brighter after perihelion than before. Referring primarily to reports on naked-eye sightings, Holetschek (1896) arrived at the same conclusion in his review investigation. However, for unknown reasons, he considered Herschel's (1847) magnitude estimate from January 26 UT "not very reliable" and altogether ignored Maclear's (1838) still brighter estimate from the previous morning (Sec. 2). Holetschek rightfully complained that most reported magnitudes referred to the nuclear condensation rather than to the comet as a whole, but bright post-perihelion nuclear magnitudes necessarily made the perihelion asymmetry even more pronounced.

Contrary to Holetschek (1896), I concluded 25 years ago that 1P/Halley was in outburst in January 1836, some 70 days after perihelion, and that the formation of "an unusually bright halo" correlated with this event (Sekanina 1983), even though I did not, at the time, recognize the similarities with 17P/Holmes in 1892-1893. In Figure 1 of Sekanina (1983), based in part on naked-eye sightings at five pre-1835 apparitions, the amplitude of Halley's outburst appeared to slightly exceed 3 magnitudes.

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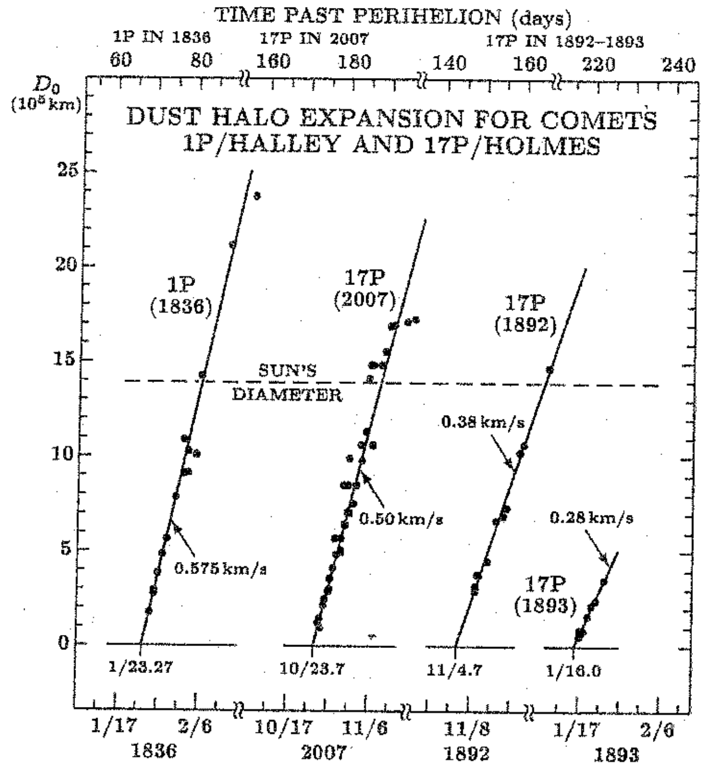

Figure 3. Expansion of the dust halo with time in the aftermath of an outburst: D_0 is the halo's linear diameter or breadth. The January 1836 event of comet 1P/Halley is compared with three similar episodes of comet 17P/Holmes: its 2007 megaburst and the 1892 and 1893 outbursts. It is only a matter of time for the expanding halo to exceed the sun's diameter, even though the mass involved is only about 10^{-20} of the sun's mass.

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On the assumption that the pre-outburst behavior of Halley's comet in 1835-1836 was the same as in 1986, it is clearly beneficial to compare the light curves from the two apparitions. To define the light curve in the critical period of time between 50 and ~ 150 days after perihelion, which covered the 1836 outburst and a possible post-outburst plateau, I collected, from issues of the *International Comet Quarterly*, more than 600 magnitude observations made by 20 selected observers between 1986 April 1 and July 14. These data were all corrected for personal and instrumental bias and reduced to a common magnitude scale of an average naked eye. In Figure 4 they are plotted as dots.

Herschel's (1847) brightness estimate from 1835 October 28 [18.7 days before perihelion (cf. Sec. 2)], when compared with the 1986 light curve at the same time from perihelion, can be used to "calibrate" his personal magnitude scale. For this purpose, I collected 10 magnitude observations made by 6 observers (all using binoculars 3 to 5 cm in aperture and all among the 20 already selected observers) between 1986 January 21.1 and 22.4 UT, or 19.36 to 18.06 days before perihelion. The normalized magnitude (as defined in Sec. 1) averaged over the 10 data points was $H_\Delta = 3.09 \pm 0.16$. Halley's nominal normalized magnitude from Herschel's observation on 1835 October 28 was 3.9, implying −0.8 mag for his personal correction. On 1836 January 26.1, Herschel estimated that the comet looked "as a bright star of the 4th, or small one of the 3rd magnitude" (Sec. 2), which, interpreted to indicate an apparent magnitude about 3.7 and a nominal normalized magnitude 2.7, gives a standard-scale normalized magnitude of $H_\Delta = 1.9$. Boguslawski's controversial observation in the morning of 1836 January 23 (Sec. 3) fits the 1986 light curve with a correction of merely −0.2 mag, yielding $H_\Delta = 4.7$. Considering the doubts expressed by Loomis (1848) about the comet's stellar appearance on 1836 January 23 (Sec. 3), one would surely expect a larger magnitude correction, comparable to or greater than Herschel's. This argument corroborates the skepticism about the authenticity of Boguslawski's observation and suggests that the comet was fainter than magnitude 6 by perhaps 0.5 to 1 mag. For Maclear's (1838) magnitude estimate of January 25, I arbitrarily adopted a correction of −0.3 (it is unlikely that the comet's brightness was overestimated by Maclear, so the correction cannot be positive; yet he estimated the comet to be much brighter than Herschel 24 hours later). This compromise leads to a standard-scale normalized magnitude of $H_\Delta = 1.2$ for January 25.1 UT, which is still 0.7 mag brighter than Herschel's corrected estimate. As it is unlikely that the comet would have faded by a factor of ~ 2 in 24 hours, the difference between the two estimates may reflect a decrease in the surface brightness of the expanding disk, in which much of the comet's light was concentrated. Indeed, if the integrated brightness on January 25 and 26 were the same, the ratio of the projected surface areas of 2.9 (Table 1) would imply a surface-brightness difference of 1.2 mag, exactly the discrepancy between Maclear's and Herschel's uncorrected magnitudes. From late January on, the difficulties experienced with estimating the brightness of Halley's comet were, because of the ever expanding halo, identical with those confronting observers of 17P/Holmes in 2007-2008. Unfamiliar with the concept of integrated (total) brightness of extended objects, the early-19th-century observers were helpless. And although it is true, as Holetschek (1896) remarked, that the threshold for naked-eye sightings was a good measure for the comet's integrated brightness near magnitude 6, even this may not have applied for an extremely extended object, which Halley's comet became from February 1836 on.

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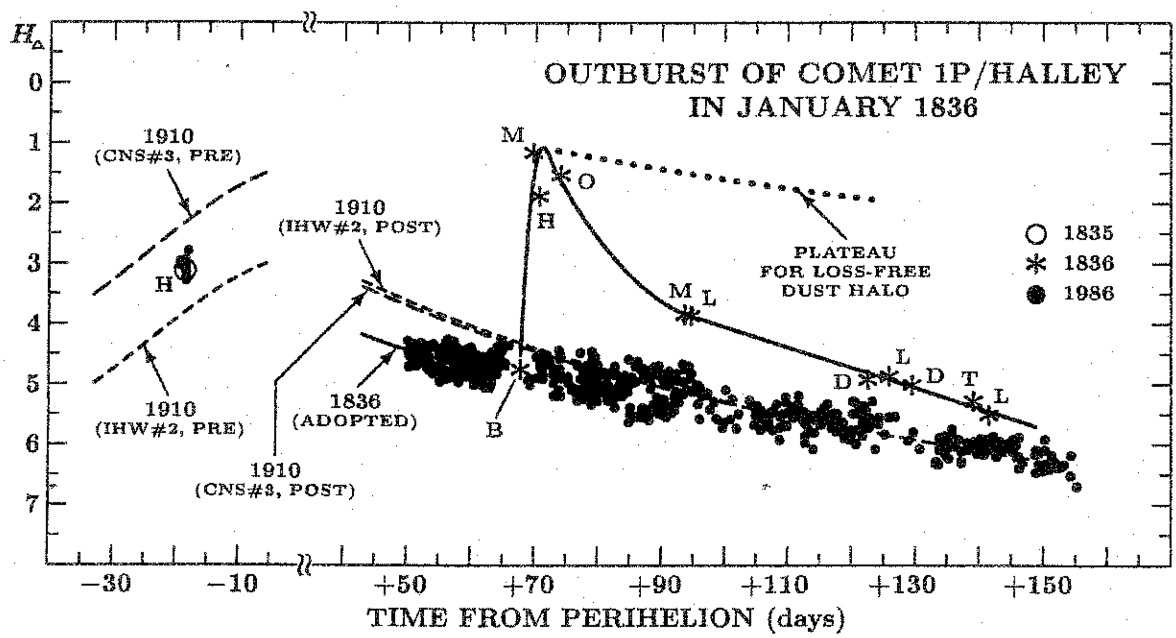

Figure 4. Light curve of comet 1P/Halley at the apparitions of 1835-1836, 1910, and 1986. Plotted versus time from perihelion is H_Δ, the visual magnitude corrected for personal and instrumental bias and normalized to a unit geocentric distance by an inverse-square power law. More than 600 magnitude estimates from 1986 April 1 through July 14 (50 through ~ 150 days after perihelion) and 10 additional ones from 1986 January 21.1-22.4 UT (about 18-19 days before perihelion) are plotted as dots. They were taken from several issues of the International Comet Quarterly. — Pre-perihelion and post-perihelion branches of two light-curve solutions for the 1910 apparition, IHW#2 and CNS#3, are shown, respectively, by the short-dashed and long-dashed curves (see text for more details). — The 1835-1836 observers whose reported magnitude estimates or naked-eye sightings of the comet are shown in the figure are marked by letters, as follows: B = P. von Boguslawski, D = E. Dumouchel, H = J. Herschel, L = E. Loomis, M = T. Maclear, O = D. Olmsted, and T = T. Taylor. Herschel's (1847) pre-perihelion magnitude estimate from 1835 October 28, plotted as a large open circle, was corrected for personal bias by comparing it with the 1986 pre-perihelion estimates from January 21-22 and used to calibrate Herschel's magnitude estimate during the outburst. The 1836 post-perihelion observations, mostly naked-eye sightings, are plotted as large asterisks. The solid curve is a model for the post-outburst light curve in 1836. Prior to the outburst the 1836 post-perihelion light curve is assumed to fit the 1986 light curve and is used to derive a magnitude correction for Boguslawski's controversial observation on 1836 January 23.2 UT, nearly 68 days after perihelion. The dotted curve is a theoretical light curve of an 1836 post-outburst plateau on the assumption of a halo that retains all the mass of injected dust. The most probable post-outburst light curve of the comet in 1836 lies in between the solid and dotted curves.

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In spite of these problems, the naked-eye sightings in 1836 showed that Halley's comet was much brighter after perihelion than before and that it was fading very slowly after the outburst. Loomis (1836, 1848) reported that D. Olmsted, his colleague at Yale, saw the comet "distinctly with his naked eye" in the morning of January 29 (near Jan. 29.4 UT). The word "distinctly" indicates that the comet (with the halo close to 10′ across at the time) was unquestionably much brighter than magnitude 5-6 and could have perhaps been of magnitude 2-3. Loomis continued by saying that during February and March he saw the comet with his naked eye about a dozen different times, last time on March 21 UT. His account is confirmed by other observers: Maclear (1838) reported that the comet was "still visible to the naked eye" on February 18.1, while Dumouchel (1836) saw it with the naked eye in the period March 17-24. In reference to the last observation of Halley's comet at Madras, on 1836 April 3.6, Taylor (1836) reported that his assistant "fancied he could see it without the assistance of the telescope when pointed out to him. — I could not see it ...". This comment may indicate a detection difference between people with sharp eyes and others; the comet's integrated brightness may have been just below magnitude 6. This is consistent with a statement by Loomis (1836) that in the evening of April 5 the comet "could not probably be seen by the naked eye; it was still visible in the finder" of a Yale telescope; it should have been brighter than magnitude 7.

The post-perihelion brightness observations in 1836 and 1986 are, in terms of the normalized magnitude H_Δ, compared in Figure 4. In addition, two solutions for the comet's light curve in 1910 are also plotted. Solution IHW#2, a light curve published by Bortle and Morris (1984), was one of the solutions used by the *International Halley Watch*. The pre-perihelion branch of this light curve came from the original work by Morris and Green (1982), while the post-perihelion branch was nearly identical with the CNS#3 solution, which was developed by Marcus in several papers in the *Comet News Service* and summarized in Marcus (1986). The pre-perihelion branch of the CNS#3 solution is about 1.5 mag brighter than the IHW#2 solution. Comparison shows that the 1986 pre-perihelion magnitude observations are about midway between the two 1910 solutions, while the 1986 post-perihelion magnitudes are generally in good agreement with either of the two 1910 solutions except when closer to perihelion, where the solutions make the comet brighter than it actually was. However, this difference in the period 50-70 days after perihelion is less than 1 mag (see Fig. 4).

Returning to the 1835-1836 light curve, Herschel's corrected and normalized "calibration" pre-perihelion data point from 1835 October 28, $H_\Delta = 3.1$, is plotted in Figure 4 as a large open circle. The 1836 post-perihelion naked-eye sightings, depicted by large asterisks, were (besides the already discussed observations by Maclear on January 25 and by Herschel on January 26) assigned a variety of magnitudes. The mid-February observations by Maclear (1838) and by Loomis (1836, 1848) were assigned magnitude 4.5, the March ones by Loomis and by Dumouchel (1836) magnitudes 5.5-5.7, and the early April ones by Taylor (1836) and by Loomis magnitudes 6.2-6.5. The dotted curve shows the decrease of the normalized brightness along a post-outburst plateau on the assumption of a constant intrinsic magnitude.

Since even the last points on the 1836 light curve, some 140 days after perihelion, lie well above the 1986 light curve, the presence of a post-outburst plateau in 1836 is very probable (Table 2). On the basis of available information, it is hard to estimate the elevation of the plateau. However, in Figure 4 the February points ($\sim$ 95 days after perihelion) are only 2-2$\frac{1}{2}$ magnitudes and the March points (120-130 days after perihelion) only 3 magnitudes below the expected loss-free plateau. Given the enormous dimensions of the expanding halo, it is conceivable that the comet was brighter than adopted in Figure 4. On the other hand, the rapid rate of Halley's halo dissipation (Sec. 5) implies that the post-outburst plateau could not survive as long as did the megaburst plateau of 17P/Holmes.

The amplitude of the outburst associated with the halo formation in Halley's comet in 1836 appears to exceed 3.5 magnitudes (Table 2). By how much is hard to say, but the amplitude was probably less than 4 magnitudes and certainly less than 5 magnitudes. In Figure 4 the nominal amplitude is 3.6 magnitudes, with a peak normalized magnitude $(H_\Delta)_{\rm peak} = +1.1$, implying a peak intrinsic magnitude $(H_0)_{\rm peak} = +0.3$, with an estimated uncertainty of about ± 0.5 mag. This result does not include the unknown phase effect and is 0.8 magnitude fainter than the peak intrinsic magnitude for the megaburst of 17P/Holmes. Using Divine *et al.*'s (1986) phase function, the corrected peak intrinsic magnitude for Halley's outburst becomes $(H_0)_{\rm peak}({\rm corr}) = -0.4$, still by about 0.5 magnitude fainter than for the megaburst of 17P/Holmes. If the particles' geometric albedo, bulk density, mass distribution function, and phase law for the two events were similar, one can crudely estimate (Table 2) that the amount of dust injected into the atmosphere of 1P/Halley during the 1836 outburst was about 60 million tons in mass, with a cross-sectional area of some 50 million km^2. This is approximately 60 percent of the amount of dust injected into the atmosphere of 17 P/Holmes during the 2007 megaburst.

Because of the light-curve uncertainties, the time of maximum brightness and the rise time in 1836 can only be estimated. The light curve probably peaked during the first four days of Maclear's and Herschel's observations, between January 25.1 and 28.1 UT, which would imply a rise time of between about 2 and 5 days (Table 2). This would be consistent with most other outbursts, including the 2007 megaburst and the 1892-1893 events of 17P/Holmes.

5. Results, Comparisons, Implications, and Conclusions

The most important result of this study is a finding that Halley's comet underwent a super-massive explosion in January 1836 that gave rise to a rapidly expanding dust halo with sharp boundaries and showed up in the light curve as a sudden flare-up followed by a prolonged, very gradual fading. The most impressive similarity is found between this event and the October 2007 megaburst of comet 17P/Holmes, including the comet's appearance and morphology during the explosion and in its aftermath, the halo's expansion velocity, and the peak intrinsic brightness. I conclude that comparable amounts of microscopic dust were injected into the atmosphere during the two events: 6×10^{13} g for 1P/Halley in 1836 and 10^{14} g for 17P/Holmes during the 2007 megaburst.

The importance of 1P/Halley as a second comet to experience a super-massive explosion *cannot be overstated*. Besides the fact that 17P/Holmes is *not unique*, Halley's example shows that the occurrence of these events is not limited to the Jupiter-family comets, with a potentially major implication for the internal structure of cometary nuclei. The example of Halley's comet also shows that super-massive explosions are not restricted *only* to objects that stay beyond 2 AU from the sun at all times and/or are slow rotators. While 17P/Holmes may or may not be spinning slowly, Halley's comet is not. The rotation state of 1P/Halley has been approximated by an excited, axially symmetric prolate spheroid (Belton *et al.* 1991), whose long axis rotates around the angular-momentum vector with a period of 3.7 days — which, with the spin around the long axis, produces a total spin period of 2.84 days.

Even though the similarities between the explosion of 1P and the megaburst of 17P cannot be in doubt, their temporal evolutions were not identical. Cursory comparison of the halos in Figures 1 and 2 suggests that the near-perfect roundness of Halley's halo became distorted already in $\sim$ 4 days after the onset of its expansion. The halo of comet 17P/Holmes began to show signs of elongated shape only $\sim$ 10 days after the onset of its expansion.

This difference further strengthens the evidence in favor of the two halos being of the same type, because it is expected on account of (i) different heliocentric distances of the two events and (ii) different phase angles under which the observations were made. A uniformly expanding cloud of dust gets distorted by solar-radiation pressure γ, which accelerates the particles in the tailward direction. During a limited period of time, $t - t_{\rm onset}$, when this effect becomes detectable, the contribution to particle motions in the direction away from the sun can be approximated by an expression proportional to $\frac{1}{2}\gamma_{\rm onset}(t - t_{\rm onset})^2$, where $\gamma_{\rm onset} = \gamma(t_{\rm onset})$. In projection onto the plane of the sky, the measured component of the effect is proportional to $\frac{1}{2}\gamma_{\rm onset} \sin\alpha_{\rm onset}(t - t_{\rm onset})^2$, where $\alpha_{\rm onset}$ is the phase angle at time $t_{\rm onset}$. Since γ varies inversely as the square of heliocentric distance r, one has $\gamma_{\rm onset} \sim r_{\rm onset}^{-2}$, and the first signs of elongated outlines of an expanding dust halo are expected to show up at time $t_{\rm elong}$, for which

$$t_{\rm elong} - t_{\rm onset} \sim (\gamma_{\rm onset} \sin\alpha_{\rm onset})^{-\frac{1}{2}} \sim \frac{r_{\rm onset}}{\sqrt{\sin\alpha_{\rm onset}}}. \qquad (1)$$

Since $r_{\rm onset} = 1.44$ AU and $\alpha_{\rm onset} = 37°$ for the 1836 outburst of 1P/Halley and, respectively, 2.44 AU and 17° for the megaburst of 17P/Holmes, the first signs of halo elongation should be detected, as measured from the onset of expansion, 2.43 times sooner for 1P than for 17P, in excellent agreement with the observations (4 days vs. 10 days). The difference between 1P and 17P is thus fully understood in terms of (i) the dependence on heliocentric distance of the radiation-pressure accelerations to which microscopic dust in the expanding halos is subjected and (ii) the effects of broadside-viewing geometry for the terrestrial observer at the time.

Other differences between the two events are due to the much-greater nuclear dimensions and considerably higher level of "normal" activity of Halley's comet. This activity accounts for a lesser amplitude of the outburst: even though the amounts of injected dust were almost comparable, 1P/Halley brightened during the explosion only by a factor of ~ 30, at most 40, rather than 400,000, as 17P/Holmes did during the megaburst. The mass of the injected dust cloud was only about a 1/4000-th part of Halley's nucleus mass (rather than more than a 1/50-th part, as in the case of 17P), when one adopts a bulk density of 0.4 g/cm^3 (used in Paper 1) and Keller *et al.*'s (1987) estimate for the volume of the nucleus.

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Table 3. Cone angle of vectorial distribution of expansion velocities of dust in the cloud of disintegrated layer 0.15 km^3 in volume lifted off from an end of the long axis of Halley's nucleus[a] as a function of the layer's thickness and base area.

Thickness (meters)	Base area (km^2)	Fraction[b] (percent)	Cone angle
50	3	$1\frac{1}{2}$	51°
30	5	$2\frac{1}{2}$	69
15	10	5	90
10	15	$7\frac{1}{2}$	104
$7\frac{1}{2}$	20	10	114
5	30	15	128

[a] Modeled as a prolate spheroid 8 km by 4 km by 4 km.
[b] Fraction of a hemispherical surface area of Halley's comet (200 km^2).

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The expanding halo of Halley's comet on Herschel's and Piazzi Smyth's drawings does not show morphology typical for ejections from small, isolated sources of activity. Thus, just as with the megaburst of 17P/Holmes, one must conclude that the dust halo of 1P/Halley was made up of inert material from an extended source on the nuclear surface and released into the atmosphere over a wide range of injection angles, mimicking an event of nearly global proportions on the scale of the nucleus. If the bulk density of 1P/Halley's nucleus is assumed to be 0.4 g/cm^3, the volume of material injected into the atmosphere during the explosion (Table 2) was 0.15 km^3. The question that needs to be addressed is this: Under what conditions on 1P/Halley's nucleus can this volume of surface terrain disintegrate and be lifted off to offer the spectacle of a cloud of microscopic dust that is scattered into a wide cone of space? This is a critical issue, given that the amount of dust in 1P/Halley's explosion is about 60 percent of the amount in the 17P megaburst and that 1P/Halley's nucleus — approximated by a prolate spheroid 16 km by 8 km by 8 km across (Keller *et al.* 1987) — is much larger than the nucleus of 17P (about 3.3 km across; see Paper 1). It turns out that the maximum desired effect on 1P/Halley is achieved when the material is removed from one of the two ends of the nucleus' long axis. The cone angle that confines the ejecta depends on the thickness of the removed block of terrain relative to the base area: the cone angle increases with decreasing thickness. Table 3 shows that, at an end of 1P/Halley's long axis, the disintegration of a layer of material 15 km^2 in area and 10 meters thick would scatter dust into a cone more than 100° wide, comparable to the effect of a layer of 5-6 km^2 in area and 50 meters thick, considered in Paper 1 for comet 17P/Holmes. Thus, the amount of released material was sufficient to mimick an extended source even on the scale of 1P/Halley's nuclear size. It should be recalled in this context that both Herschel (1847) and Maclear (1838) reported on several occasions that the nuclear condensation was nearer the halo's southern limb than the northern one and that the surface brightness varied from spot to spot in the halo. While this information cannot be exploited for quantitative modeling, it indicates an asymmetry in the vectorial distribution of expansion velocities and fluctuations in the amount of mass injected in different directions, with implications for inhomogeneities in the morphology of the extended source and azimuthal changes in the cone angle.

The orbital position of Halley's comet at the time of the 1836 explosion, 67.8 days after perihelion and 1.44 AU from the sun (Table 2), is in line with the results in Paper 1 for both the 2007 megaburst and the 1892-1893 events of comet 17P/Holmes, and it is favorable to the physical scenario proposed in Paper 1. Because of substantial lags necessarily involved in the process of penetration by a thermal wave into the interior of the nucleus, the post-perihelion occurrence of these episodes is indeed to be expected. Information available on 1P/Halley's explosion is broadly consistent with the injection mechanism in which the trigger is an exothermic reaction caused by a transition of water ice from amorphous phase to cubic phase in a subsurface reservoir, located under the layer of terrain that is to disintegrate into the cloud of microscopic dust. As with the events of 17P/Holmes, the precipitous crumbling must occur almost instantly upon the lift-off from the surface, in order that a large fraction of dust particles can be accelerated to subkilometer-per-second velocities. For the related issues of the nature of lifted material and other details the reader is referred to Paper 1.

For the sake of comparison, the major outburst that Halley's comet was observed to have experienced in 1991 some 14 AU from the sun, with a surviving crescent-shaped halo (West *et al.* 1991), cannot rival the 1836 event. The expansion velocity was a factor of 40 lower, and the mass of dust injected was a factor of nearly 10^3 smaller. Regardless of the mechanism involved (Prialnik and Bar-Nun 1992, Sekanina *et al.* 1992), that episode was distinctly a local event.

One can expect that, in due time, more comets enduring super-massive explosions will be discovered and recognized. It is hoped that the relationships among these comets, ordinary split comets, and comets subjected to cataclysmic fragmentation will prove helpful in providing more insights in our quest to understand the processes of aging and disintegration of these bizarre solar-system members.

Acknowledgements

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Tabulation of Comet Observations

As noted in the January issue, all of the tabulated data attached to that issue consisting of observations of comet 17P in February and March have their descriptive information given below.

Descriptive Information, to complement the Tabulated Data (all times UT):

See the July 2001 issue (page 98) for explanations of the abbreviations used in the descriptive information.

◇ *Comet 8P/Tuttle* ⟹ 2007 Nov. 28.74, Dec. 4.77, 13.68, 2008 Jan. 4.71, 11.83, and 12.73: `Guide 8.0` software used for comp.-star mags [SAN07]. 2007 Nov. 30.73: `Guide 8.0` software used for comp.-star mags [MAJ01]. Dec. 3.84, 4.81, 5.80, 6.74, and 13.73: `Guide 8.0` software used for comp.-star mags [VAS06]. Dec. 13.81: GUIDE 7.0 software used for comp.-star mags [SAR02]. Dec. 19.04, 2008 Jan. 6.74, 7.84, 8.75, 10.75, 15.72, and 26.74: `Guide 8.0` software used for comp.-star mags [SZA]. 2008 Jan. 7.84, 8.85, and 26.75: `Guide 8.0` software used for comp.-star mags [TOT03]. Jan. 13.39 and 26.39: `The Sky` ver. 5 software used for comp.-star mags [MIT]. Jan. 14.47, 24.45, and 27.41: `StellaNavigator` ver. 8.1 software used for comp.-star mags [NAG08]. Jan. 17.06: comet also seen in 8×56 B; fairly diffuse, no tail [NOW]. Jan. 24.45: $B-V$ values of comp. stars were +0.60, +0.61, and +0.78 [NAG08]. Feb. 1.08: comp. stars have $V = 6.67$ ($B-V = +0.16$) and 7.20 (−0.01) [GOI]. Feb. 1.98, 2.99, 6.01, 7.03, and 8.98: comp. stars have $V = 6.67$ ($B-V = +0.16$) and 6.87 (+0.96) [AMO01]. Feb. 1.98 and 3.97: comp. stars have $V = 6.67$ ($B-V = +0.16$) and 7.20 (−0.01) [GOI]. Feb. 4.97 and 5.99: comp. stars have $V = 6.67$ ($B-V = +0.16$) and 7.29 (+0.54) [GOI]. Feb. 5.47: hazy high cloud [SEA]. Feb. 8.04 and 13.97: clouds interfering [GOI]. Feb. 8.04: comp. stars have $V = 6.76$ ($B-V = +0.54$) and 7.29 (+0.54) [GOI]. Feb. 9.00, 10.97, and 13.97: comp. stars have $V = 6.76$ ($B-V = +0.54$) and 7.29 (+0.54) [GOI]. Feb. 13.97, 18.99, 19.97, Mar. 16.97, 18.01, 20.95, Apr. 16.98, 17.95, and 18.96: moonlight [GOI]. Feb. 13.97, 15.98, 16.97, and 18.97: comp. stars have $V = 6.52$ ($B-V = -0.01$) and 6.85 (+0.37) [AMO01]. Feb. 15.98, 16.97, 24.97, and 25.99: clouds interfering [AMO01]. Feb. 18.97, 19.98, Mar. 13.97, 16.99, Apr. 14.95, and 18.00: moonlight interference [AMO01]. Feb. 18.97: comp. star has $V = 7.59$ ($B-V = +0.39$) [AMO01]. Feb. 18.99 and 19.97: comp. stars have $V = 6.72$ ($B-V = +0.46$) and 7.31 (+0.26) [GOI]. Feb. 19.98: comp. stars have $V = 6.85$ ($B-V = +0.37$) and 7.59 (+0.39) [AMO01]. Feb. 24.97 and 25.99: comp. stars have $V = 6.85$ ($B-V = +0.37$) and 7.11 (+0.54) [AMO01]. Feb. 24.98, 26.01, and 26.98: comp. stars have $V = 7.11$ ($B-V = +0.54$) and 7.55 (+0.54) [GOI].

Mar. 1.98: comp. stars have $V = 7.33$ ($B-V = +0.83$) and 7.73 (−0.12) [GOI]. Mar. 2.00: moonlight interference [SOU01]. Mar. 2.97: comp. stars have $V = 7.33$ ($B-V = +0.83$) and 7.55 (+0.58) [GOI]. Mar. 4.00, 4.96, and 6.00: comp. stars have $V = 7.73$ ($B-V = -0.12$) and 7.55 (+0.58) [GOI]. Mar. 7.96: comp. stars have $V = 7.11$ ($B-V = +0.54$) and 7.73 (−0.12) [GOI]. Mar. 8.96, 9.95, and 13.97: comp. stars have $V = 7.33$ ($B-V = +0.83$) and 7.84 (+0.23) [AMO01]. Mar. 8.97: comp. stars have $V = 7.53$ ($B-V = +0.40$) and 7.73 (−0.12) [GOI]. Mar. 16.97, 18.01, and 20.95: comp.