Recurrence of Super-Massive Explosions and Orbital Evolution of Comet 17P/Holmes: I. Missed 1913-1957 Returns to the Sun

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Abstract. *This paper is the first part of an investigation whose goal is to find out whether the enormous explosions experienced by comet 17P/Holmes in 1892-1893 and 2007 were accidental events or diagnostic of a systematic and possibly periodic or quasi-periodic pattern that extends over much longer time spans. In search of a recurrence rate, the specific objective of this paper is to establish the degree of likelihood that additional explosions — potentially missed on account of the comet's very incomplete observing record — may have occurred during the 115 years that separate the two known events. This effort consists of: (i) a determination of the comet's motion between the end of the 19th century and now, resulting in the best possible sets of orbital elements for the missed returns; (ii) an examination of observing conditions at each missed return for detecting a major explosion; (iii) a compilation of reported instances of unsuccessful search for the comet under favorable circumstances; and (iv) an investigation of potential causes of failure (inaccurate ephemeris, comet too faint) and identification of the most probable cause in each case. Indicative of a true recurrence period (if there is one) and vitally important to the second part of this investigation addressing the comet's history prior to the late 19th century, the scrutinized evidence shows that there is virtually no chance of an additional major explosion having occurred between 1892-1893 and 2007, at a well-observed apparition or a missed return alike. Recurring of super-massive explosions of comet 17P on a time scale much shorter than 115 years is practically ruled out.*

1. Introduction

In a recent study (Sekanina 2008a), I defined a *super-massive explosion* (also referred to in this paper as a *major explosion*) of a comet as a violent event during which the mass of dust suddenly (over several days, as a rule) injected into the comet's atmosphere amounts to at least 10^{13} gram. Observationally, a major explosion is recognized (i) by a prominent, sharply-bounded dust halo, which for days and possibly weeks expands nearly uniformly at a subkilometer-per-second velocity; and (ii) by a peak intrinsic brightness (*i.e.*, normalized to unit geocentric and heliocentric distances by an inverse square power law), which is not fainter than magnitude $(H_0)_{\rm peak} = 2$. A major explosion may consist of more episodes, each of a similarly short duration, separated by up to a number of weeks. The brightness increase is detected as an outburst, whose amplitude depends on the comet's level of general activity at the time of the event's onset. If the brightness increases by a factor of more than $\sim 10^4$, the event (or its episode) may be called a *megaburst*.

At present, super-massive explosions are known to have been experienced by only two comets, 17P/Holmes and 1P/Halley (Sekanina 2008a, 2008b = Paper 1); in either case the comet survived, becoming a naked-eye object for a limited period of time. While events of these proportions occur infrequently, they may be a subcategory of a more commonly observed phenomenon — nuclear fragmentation, which is usually accompanied by a less prominent outburst, with $(H_0)_{\rm peak} \gg 2$ (Sekanina 2007, 2008c; Paper 1).

Comet 17P/Holmes, ordinarily an intrinsically faint member of the Jupiter family of comets that currently orbits the sun with a period of nearly 7 years, remains to this day the only comet known to have undergone more than one super-massive explosion, even though the history of observation of 17P is relatively short and includes only 10 apparitions (see below; also, *e.g.*, Marsden and Williams 2008; Paper 1; Sekanina 2009 = Paper 2).

2. Recurrence of Super-Massive Explosions

Comet 17P/Holmes was discovered in 1892 while flaring up during the first of two major discrete episodes, ~ 10 weeks apart, that made up the comet's first observed super-massive explosion. A minor outburst during the next (1899) apparition (cf. Paper 2) may also have been part of the same global event, a scenario that is consistent with the proposed mechanism (cf. Paper 1). The second super-massive explosion of 17P/Holmes was the spectacular megaburst of 2007, which occurred almost exactly 115 years after the first event. Questions that immediately come to one's mind are: *Is this recurrence of major explosions accidental or is it diagnostic of a long-term, systematic pattern? If these events do not happen by chance, do they make up a sequence with an inherent periodicity or quasi-periodicity? And if they do, is their characteristic period equal, at least approximately, to 115 years or to a shorter interval that is a submultiple thereof?*

Any major effort aimed at answering these questions requires that two formidable tasks be addressed. The first task, examined in this paper, is presenting convincing arguments in favor of, or against, the existence of additional explosions of such enormous proportions between 1892-1893 and 2007. The second task, the subject of a follow-up paper, involves a time consuming search for similar major explosive events in historic records of naked-eye comets. Both tasks demand, as a prerequisite, that the comet's orbital motion be quite well understood over the relevant periods of time. The history of orbit determination of comet 17P/Holmes, the first topic to be dealt with below, is illuminating — as it explains the peculiar history of observation of this object: after having been safely recovered in 1899 and 1906, the comet was subsequently lost for nearly 60 years. The reason was nothing short of a blunder, whose implications could — unless shown otherwise — adversely affect conclusions on additional super-massive explosions between 1892-1893 and 2007.

3. History of Post-1892 Search for Comet 17P/Holmes, and Orbit Predictions

Besides a number of preliminary sets of orbital elements, calculated by several computers (including A. Berberich, H. Kreutz, L. Schulhof, and E. Weiss) in the course of the discovery apparition, the major task of determining a definitive orbit for the 1892-1893 apparition was undertaken independently by Zwiers (1895a) and by Kohlschütter (1896a, 1896b). As was common practice in those days, they both used normal places — Kohlschütter averaging 670 astrometric observations into 13 normal places, and Zwiers 510 into 10 normal places. Kohlschütter accounted for the perturbations by all planets except Mercury, while Zwiers included only those by Jupiter, Earth, and Mars. A polemic evolved between the two computers (Zwiers 1897, Kohlschütter 1897) that concerned the differences between their results, focusing (i) on the corrections applied by Kohlschütter in his work to account for systematic errors made by observers when bisecting diffuse images of the comet and (ii) on a large number of observations eliminated by Kohlschütter in his final solution. Zwiers (1897) used this opportunity to further refine his set of definitive elements.

Unfortunately, Kohlschütter (1896a, 1896b) did not extend his account of the planetary perturbations beyond 1892-1893 and provided no prediction for the comet's next return to the sun in 1899.[1] On the other hand, Zwiers (1895a, 1895b) accounted for the gravitational effects by Jupiter, Earth, and Mars until December 1893, by Jupiter, Saturn, and Earth from then on until July 1896, and by Jupiter and Saturn afterwards. He went on to publish an ephemeris for 1899 (Zwiers 1899a), which, after Perrine's (1899) recovery of the comet in June of that year, was improved by applying a perihelion-time correction ΔT of about +0.4 day to fit the observed motion (Kreutz 1899; Zwiers 1899b, 1899c, 1900).

After Zwiers (1902) published his first orbit linking the 1892 and 1899 apparitions, he began to work on a prediction for the comet's next return in 1906. He first recalculated the perturbations, between 1892 and 1900, by "all the planets of which the disturbing effect could not a priori be neglected" (Zwiers 1905). This work remained incomplete because of time constraints and only the Jovian perturbations between 1900 and 1906 were included in the predicted orbital elements and ephemeris for 1906-1907 (Zwiers 1905, 1906a, 1906b, 1907). In spite of the approximations in the calculation of planetary perturbations, Wolf's (1906a) recovery of the comet at the Königstuhl Observatory near Heidelberg in late August 1906 indicated that the predicted orbit required a correction ΔT of only −0.09 day in the perihelion time (Zwiers 1906c). The photographic recovery and subsequent observations at the Königstuhl Observatory (see Paper 2 for details) were a masterful achievement at the time, considering that the comet was searched unsuccessfully both by Aitken (1907) with the 91-cm refractor of the Lick Observatory several times in August and September 1906 (comet fainter than magnitude 15) and by Wirtz (1907) with the 49-cm refractor of the Strasbourg Observatory on October 22, always under favorable observing conditions.

It is unfortunate that in his last three papers on comet 17P/Holmes, Zwiers (1912a, 1912b, 1912c) committed a fatal *faux pas* by using his orbital set for 1892-1906 with no planetary perturbations applied throughout 1906-1913 to predict the comet's next return to the sun. As demonstrated fourteen years later by Polak (1926), the consequence of this inexcusable omission (time constraints notwithstanding) was disastrous. Polak showed that, because of the comet's approach to Jupiter to 0.54 AU in December 1908, the orbit underwent dramatic changes, and in 1913 the passage through perihelion occurred nearly *6 months* later than predicted by Zwiers (1912a, 1912b). Not surprisingly, Phillips (1914) complained that "nothing appears to have been seen" of the comet.

As if this were not troublesome enough, an ephemeris for the comet's 1920 return, published by Ebell (1919, 1920), was based on the same set of orbital elements as the 1913 ephemeris by Zwiers. Professing that there was *no* close approach to Jupiter since 1906, Ebell ignored the planetary perturbations accumulated over *two* revolutions about the sun. The perihelion time was now off by almost a whole year! Schorr (1919) reported that W. Baade found, in the comet's orbit, a nebular object on two plates exposed on 1919 December 10 with the 100-cm reflector of the Hamburg Observatory in Bergedorf, but that the offset from Ebell's ephemeris was more than 2° in declination. Although the suggestion that Baade's exposures might have shown comet 17P/Holmes was soon retracted (Schorr 1920), the object was officially designated as comet 1919f (*e.g.*, Crommelin 1920). The nature of Baade's object remained unknown for more than 50 years (!), until Marsden (2009, personal communication) identified it with the minor planet *(137) Meliboea* in the 1970s. It was apparently not possible for Baade to distinguish between a faint comet and a minor planet, because the 100-cm $f/3$ reflector in Bergedorf — like any large-aperture, high f-ratio reflecting telescope of the early 20th century — showed bloated, coma-distorted images of all objects except those very near the center of the photographic field (*e.g.*, Mulherin 2007).

Competent scientific practices returned with Polak's (1926) investigation, who accounted for the Jovian perturbations in the period of 1906-1913 and corrected the perihelion times for the 1913 return and, approximately, for 1920. In a follow-up paper, Polak (1928) derived a set of orbital elements and an ephemeris for the comet's 1928 return after having recomputed the perturbations by Jupiter and Saturn from 1899 to 1906 and having extended the Jovian perturbations from 1906 to 1928. An independent orbit determination for this return was presented by Cripps (1927), who started his calculations with Polak's (1926) orbit for the 1913 return and calculated the 1913-1928 perturbations by Jupiter. Polak's

[1] Both Zwiers (1895a) and Kohlschütter (1896a, 1896b) listed an 1899 perihelion time with their definitive elements for 1892-1893, but from the context it is obvious that this time refers to the 1892 osculation epoch used — which serves only for general information and comparison, and is not meant to predict the comet's actual passage through perihelion in 1899.

and Cripps' predicted perihelion times differed by only a few days, yet the comet was searched for unsuccessfully, as reported by Crommelin (1929) in general and by Van Biesbroeck (1928a) in particular. Van Biesbroeck remarked that the field of Polak's prediction "was examined photographically in September . . . but no clear evidence of the presence of the comet has been found". Inspection of Van Biesbroeck's 60-cm Yerkes reflector[2] observing records (whose copy for the whole period of 1922-1963 is in the possession of this author) shows that the observer's 1928 search for comet 17P/Holmes consisted of two 36-minute exposures on 1928 September 16 and two 35-minute exposures on September 25 (see Sec. 6 below).

An extension of the orbital prediction for the return of 1935 was published by Foxell and McNeile (1934), who applied the perturbations by Jupiter and Saturn between 1928 and 1935. However, 17P/Holmes is not listed by Crommelin (1936) among the periodic comets, for which search ephemerides were published and were unsuccessfully sought for in 1935. Van Biesbroeck (1935) pointed out that "the chances of recovery are very small" and his Yerkes observing book shows that he made no attempt to locate the comet at this return.

No search ephemeris was available in time for the 1942 return. Although Porter (1941) expressed his skepticism about chances of the comet's recovery, he reported that an ephemeris was being prepared by J. T. Foxell and K. Pollock, which apparently was never published. However, Polak (1949, 1950),[3] who resumed his work on comet 17P/Holmes in 1943, calculated the Jovian perturbations from 1935 on and belatedly determined a set of 1942 elements and ephemeris as part of his effort to predict the comet's orbit and provide an ephemeris for the 1950 return. Polak's (1950) ephemeris for 1950 was used by D. J. Martynov (Editors 1950, Merton 1951) to search for the comet photographically in September and October 1950 with the 38-cm $f/2.4$ Schmidt camera of the Engelhardt Observatory in Kazan, U.S.S.R., with no success for a limiting magnitude of 15. From the camera's description (Martynov 1951), it appears that photographs have a scale of 221″ per mm and a covered field of up to 7°.1 in diameter; that the diameter of a vignetting-free field is about 4°, with only a minor effect farther from the optical axis; and that on blue-sensitive Agfa Astro plates, 13 cm by 13 cm in size, a limiting magnitude 15 is reached with an exposure of about 2 minutes.

In the meantime, Koebcke (1948) published the first part of his orbital investigations of comet 17P/Holmes, which deals with the 1892-1906 apparitions. Koebcke used Zwiers' original normal places in 1892-1893 and 1899-1900, and the four individual positions in 1906. He also used some of Zwiers' perturbation calculations, which he combined with his own, including a derivation of the perturbations by Uranus and Neptune and a mean effect of the four inner planets throughout 1892-1906. Koebcke obtained an improved set of orbital elements, but the work was planned to continue, with the definitive orbit and another round of perturbation computations scheduled for a second part of the investigation. I have been unable to find this paper's continuation, and it may never have been published.

After the failure of the 1950 search, it appears that a consensus was reached that comet 17P/Holmes had been lost, as it is not on Porter's (1958) list of comets searched for unsuccessfully during 1957. Yet, this sad saga of frustrated efforts concluded happily. Marsden's (1963) reexamination of the motion of 17P as one of seven long-lost comets, one of the earliest instances of fully automated use of a high-speed electronic computer in comet search and orbit determination led to a successful recovery of 17P. Only the perturbations by Jupiter and Saturn were accounted for rigorously, while the perturbations by Venus, Earth, and Mars were determined using approximations, and those by Mercury, Uranus, and Neptune were neglected. After seven missed returns, the predicted 1964 and 1972 perihelion times were expected by Marsden not to be in error by more than two or three days. And although this comet was considered a case of greater-than-average difficulty among the seven long-lost comets, it was actually the first to be recovered: using Marsden's ephemeris, Roemer (1964) found it with the 102-cm reflector of the U.S. Naval Observatory at Flagstaff, Arizona, as an object of magnitude ~19 on two plates exposed on 1964 July 16, with confirming images from July 17 and September 11. The initial correction to Marsden's predicted time of perihelion passage was only +0.7 day, apparently still an overestimate (Sec. 4). Since 1964 the comet has been recovered at every single return to perihelion and is now secure.

4. Motion of Comet 17P/Holmes Between 1892 and 2009

The orbital sets referred to in Sec. 3, whether predicting the comet's motion successfully or not, have all been gravitational solutions. The fact that Marsden's (1963) prediction — spanning 11 revolutions about the sun between 1892 and 1972 — required a positive correction ΔT suggests that the comet's orbital motion has probably been affected by a nongravitational deceleration. As astrometric observations from an ever-growing number of returns became available, the magnitude of this nongravitational deceleration has for some time now been well determined. I am aware of three sets of nongravitational solutions for comet 17P that link six or more apparitions: one by Marsden (2005), based on 139 observations from 1964-2001; a second by Kinoshita (2009), based on 3311 observations from 1964-2009; and a third, posted on the *JPL Solar System Dynamics* website that is at present maintained and updated by Mastrodemos (2009); at the time of writing, this set is based on 3581 observations from 1964-2009 (Orbit K077/21).[4]

Since no successful attempt to incorporate the apparitions 1892-1906 into an overarching solution linking all apparitions of comet 17P is available, I adopt the JPL orbit K077/21 as a "working" set of elements, integrate it back and forward in time, and refer to it as *the JPL orbit*. The osculating elements for the returns 1892-2014 are listed in

[2] Even though this telescope is usually referred to as a 24-inch (or 61-cm) reflector, its actual full aperture has a diameter of 597 mm, or 23.5 inches; with the focal length of 2360 mm, or 92.9 inches, this is an $f/3.95$ Newtonian system that has a plate scale of 87″.4 per mm (*e.g.*, Farnsworth 1928).

[3] J. Polak and I. F. Polak are the same person, a Russian scientist *Iosif Fedorovich Polak*.

[4] A new solution, K077/22, links all 10 apparitions, from 1892 to 2009, but leaves unacceptably large residuals, up to 6′, from all observations in 1906.

Table 1. Predicted osculating orbital elements for comet 17P/Holmes at 18 returns to the Sun between 1892 and 2014 (eq. J2000.0).[a,b,c]

Epoch (ET)	1892 July 1.0	1899 Apr. 16.0	1906 Mar. 11.0
Epoch JD	2412280.5	2414760.5	2417280.5
T (ET)	1892 June 13.9948	1899 Apr. 28.5882	1906 Mar. 14.6448
ω (deg)	14.2728	14.0581	14.2572
Ω (deg)	333.2205	333.1429	333.0808
i (deg)	20.9057	20.8159	20.8277
q (AU)	2.140488	2.127756	2.120915
e	0.409534	0.411348	0.412345
P (yr)	6.90	6.87	6.86
Epoch (ET)	1913 July 12.0	1920 Nov. 12.0	1928 Mar. 15.0
Epoch JD	2419960.5	2422640.5	2425320.5
T (ET)	1913 July 13.9628	1920 Nov. 20.1709	1928 Mar. 26.2398
ω (deg)	21.7837	21.8886	21.7796
Ω (deg)	330.8087	330.7528	330.7454
i (deg)	19.5854	19.5633	19.5739
q (AU)	2.342314	2.353267	2.344148
e	0.379521	0.378359	0.379835
P (yr)	7.33	7.37	7.35
Epoch (ET)	1935 July 17.0	1942 Nov. 17.0	1950 Feb. 8.0
Epoch JD	2428000.5	2430680.5	2433320.5
T (ET)	1935 July 16.1153	1942 Nov. 5.0176	1950 Feb. 26.0815
ω (deg)	21.5769	21.8264	21.7159
Ω (deg)	330.5854	330.4978	330.3196
i (deg)	19.5924	19.5890	19.5334
q (AU)	2.317942	2.316843	2.346922
e	0.383781	0.383827	0.379202
P (yr)	7.30	7.29	7.35
Epoch (ET)	1957 July 21.0	1964 Nov. 21.0	1972 Feb. 13.0
Epoch JD	2436040.5	2438720.5	2441360.5
T (ET)	1957 July 5.9377	1964 Nov. 15.9280	1972 Jan. 30.8192
ω (deg)	21.6816	21.7928	23.4267
Ω (deg)	330.2948	330.2607	328.1684
i (deg)	19.5021	19.5237	19.2238
q (AU)	2.360418	2.346950	2.155165
e	0.377085	0.378896	0.413638
P (yr)	7.38	7.35	7.05
Epoch (ET)	1979 Feb. 16.0	1986 Mar. 31.0	1993 Apr. 3.0
Epoch JD	2443920.5	2446520.5	2449080.5
T (ET)	1979 Feb. 22.6597	1986 Mar. 14.1313	1993 Apr. 10.7413
ω (deg)	23.5904	23.3295	23.2218
Ω (deg)	328.0874	328.0496	328.0460
i (deg)	19.2103	19.1908	19.1703
q (AU)	2.159998	2.168456	2.176755
e	0.413117	0.411815	0.410414
P (yr)	7.06	7.08	7.09
Epoch (ET)	2000 May 16.0	2007 May 20.0	2014 Apr. 13.0
Epoch JD	2451680.5	2454240.5	2456760.5
T (ET)	2000 May 11.8181	2007 May 4.4967	2014 Mar. 27.4738
ω (deg)	23.3471	24.2577	24.5135
Ω (deg)	328.0100	326.8674	326.7649
i (deg)	19.1878	19.1132	19.0916
q (AU)	2.165489	2.053162	2.056575
e	0.412021	0.432431	0.431860
P (yr)	7.07	6.88	6.89

[a] Based on the JPL elements K077/21, calculated by N. Mastrodemos and fitting 3581 astrometric observations between 1964 July 16 and 2009 March 25 with an RMS residual of $\pm 0.68''$.

[b] The solution accounts for the perturbations by all nine planets, the relativistic effect, and the nongravitational effects whose parameters are $A_1 = (+0.2475 \pm 0.0049) \times 10^{-8}$ days/AU^2 and $A_2 = (+0.03124 \pm 0.00025) \times 10^{-8}$ days/AU^2.

[c] The individual rows list: the date of osculating epoch (in ephemeris time); its Julian date JD; T, the time of perihelion passage (in ephemeris time); ω, the argument of perihelion (in degrees); Ω, the longitude of the ascending node (in degrees); i, the orbital inclination (in degrees); q, the perihelion distance (in astronomical units); e, the orbital eccentricity; and P, the orbital period (in years). The originally chosen epoch was 2008 Dec. 1.0 ET and the formal errors of the elements were ± 0.00011 day in T, $\pm 0.000047°$ in ω, $\pm 0.000037°$ in Ω, $\pm 0.0000047°$ in i, ± 0.00000095 AU in q, and ± 0.00000026 in e.

Table 2. List of the perihelion times of comet 17P/Holmes from fitted and predicted sets of orbital elements for the period of time 1892–2014.

No. of return to Sun	Time of perihelion (UT or ET): Author's result[a]	Time of perihelion (UT or ET): JPL−Auth.	Epoch of osculation[b,c] (UT or ET)	Observations in orbital solution	Reference to author of orbital solution
1	1892 June 13.821	+0.099	1892 Nov. 4.5	1892–1893	Zwiers (1895a)
	13.979	−0.091	Dec. 11.46	1892–1893	Kohlschütter (1896a, 1896b)
	13.856	+0.064	Nov. 4.5	1892–1893	Zwiers (1897)
	13.891	+0.032	1.0	1892–1906	Koebcke (1948)
	13.951	+0.044	July 1.0	1892–1906	Williams (1999)
	13.931*p*	+0.064	1.0*	1964–2009	Kinoshita (2009)
2	1899 Apr. 27.973*p*	+0.628	1899 Jan. 12.5	1892–1893	Zwiers (1895b)
	28.165*p*	+0.424	Sept. 9.5	1892–1893	Zwiers (1899a)
	28.555	+0.034	9.5	1892–1899	Zwiers (1899c)
	28.599	−0.010	9.5	1892–1900	Zwiers (1902, 1905)
	28.599	−0.010	6.0	1892–1906	Koebcke (1948)
	28.594	−0.006	Apr. 16.0	1892–1906	Williams (1999)
	28.565*p*	+0.024	16.0*	1964–2009	Kinoshita (2009)
3	1906 Mar. 14.680*p*	−0.044	1906 Jan. 16.5	1892–1900	Zwiers (1905)
	14.594	+0.042	16.5	1892–1906	Zwiers (1906c)
	14.746	−0.060	Aug. 21.0	1892–1906	Koebcke (1948)
	14.696	−0.051	Mar. 11.0	1892–1906	Williams (1999)
	14.663*p*	−0.018	11.0*	1964–2009	Kinoshita (2009)
4	1913 Jan. 21.2*p*	(+173.4)	1912 June 15.5	1892–1906	Zwiers (1912a, 1912b)
	July 13.169*p*	+0.795	1913 July 15.5	1892–1906	Polak (1926)
	13.424*p*	+0.540	15.5	1892–1906	Polak (1928)
	13.965*p*	−0.002	12.0*	1964–2009	Kinoshita (2009)
5	1919 Nov. 30.8*p*	(+355.4)	....	1892–1906	Zwiers (1912b), Ebell (1919)
	1920 Nov. 11.43*p*	+8.74	(1906 Jan. 16.5)	1892–1906	Polak (1926)
	20.182*p*	−0.011	1920 Nov. 12.0*	1964–2009	Kinoshita (2009)
6	1928 Mar. 22.63*p*	+3.62	1928 Feb. 27.0	1892–1906	Cripps (1927)
	25.807*p*[d]	+0.453	8.0	1892–1906	Polak (1928)
	26.259*p*	−0.019	Mar. 15.0*	1964–2009	Kinoshita (2009)
7	1935 July 11.20*p*	+4.92	....	1892–1906	Foxell and McNeile (1934)
	16.137*p*	−0.022	1935 July 17.0*	1964–2009	Kinoshita (2009)
8	1942 Oct. 25.53*p*	+10.59	1943 Dec. 17.0	1892–1906	Polak (1950)
	Nov. 5.036*p*	−0.019	1942 Nov. 17.0*	1964–2009	Kinoshita (2009)
9	1950 Feb. 15.97*p*	+10.09	1950 Apr. 24.0	1892–1906	Polak (1950)
	26.087*p*	−0.006	Feb. 8.0*	1964–2009	Kinoshita (2009)
10	1957 July 5.924*p*	+0.014	1957 July 21.0*	1964–2009	Kinoshita (2009)
11	1964 Nov. 15.4*p*	+0.53	....	1892–1906	Marsden (1963)
	15.9283	−0.0003	1964 Nov. 21.0*	1964–2001	Marsden (2005)
	15.9283	−0.0003	21.0*	1964–2009	Kinoshita (2009)
12	1972 Jan. 30.4*p*	+0.42	....	1892–1906	Marsden (1963)
	30.8203	−0.0011	1972 Feb. 13.0*	1964–2001	Marsden (2005)
	30.8198	−0.0006	13.0*	1964–2009	Kinoshita (2009)
13	1979 Feb. 22.6618	−0.0021	1979 Feb. 16.0*	1964–2001	Marsden (2005)
	22.6607	−0.0010	16.0*	1964–2009	Kinoshita (2009)
14	1986 Mar. 14.1341	−0.0028	1986 Mar. 31.0*	1964–2001	Marsden (2005)
	14.1325	−0.0012	31.0*	1964–2009	Kinoshita (2009)
15	1993 Apr. 10.7442	−0.0034	1993 Apr. 3.0*	1964–2001	Marsden (2005)
	10.7424	−0.0011	3.0*	1964–2009	Kinoshita (2009)
16	2000 May 11.8205	−0.0024	2000 May 16.0*	1964–2001	Marsden (2005)
	11.8188	−0.0007	16.0*	1964–2009	Kinoshita (2009)
17	2007 May 4.4995*p*	−0.0028	2007 May 20.0*	1964–2001	Marsden (2004)
	4.4975	−0.0008	20.0*	1964–2009	Kinoshita (2009)
18	2014 Apr. 27.4751*p*	−0.0013	2014 Apr. 13.0*	1964–2009	Kinoshita (2009)

[a] Time predicted from observations at other returns is designated by *p*. From 1957 on, all times are ET. The adopted ET−UT does not exceed ∼0.0003 day between 1892 and 1957.
[b] When no osculating epoch is published (dotted line), it is assumed to coincide with the perihelion time.
[c] Asterisk indicates an orbital solution with nongravitational terms included.
[d] Polak's (1928) published time of perihelion passage, 1928 Mar. 24.56 UT, differs by 1.247 days from the value, calculated from Polak's results for the mean anomaly of the osculation epoch and the daily mean motion. Reconstruction of Polak's ephemeris with each of the two perihelion times shows that the ephemeris agrees with the latter, tabulated time.

(text continued from page 47)

Table 1, with information on the orbital solution in the footnotes. The ultimate purpose of this exercise — to examine unsuccessful searches after 1906 and before 1964 (Secs. 5-7, 8.2-8.3) — requires that the comet's motion between 1892 and 2009 — the perihelion times in particular — be approximated as closely as possible. Comparison with sets of orbital elements based on actual astrometric observations from 1892-1906 offers tests of, and clues to, the extrapolation qualities of the JPL orbit. Also of much interest is comparison with numerous predicted orbits for the returns at which the comet was missed, since these predictions were used in the searches and should offer an insight into the causes of the search failures.

These comparisons are incorporated into Table 2, which also provides information on the merits of the three solutions with the nongravitational terms. The columns are self-explanatory; accepting the JPL orbit as a reference set, column 3 lists the correction ΔT to the perihelion time required by the listed orbital solution. The 1892-1893 definitive orbital sets are, together with the best available two-apparition orbit (Zwiers 1902, 1905), the most critical for assessing the quality of the JPL orbit, considering the fact that fitting astrometric observations of short-period comets from one (two) return(s) to the sun never (only seldom) requires nongravitational terms.

A scatter of nearly 0.2 day among the perihelion times of the three 1892 definitive orbits (first three entries in Table 2) needs a few words of explanation. The formal errors from Kohlschütter's (1896a, 1896b) and Zwiers' (1895a, 1897) definitive orbits for 1892-1893 are both about ±0.1 day, which, as Table 2 shows, are also their deviations from the JPL orbit. The reason for these discrepancies is the comet's discovery nearly 5 months after perihelion, thus involving an extrapolation. When I integrated the planetary perturbations for Kohlschütter's (1896a, 1896b) orbit from 1892 to 1899, I found that it predicted the comet to pass perihelion on 1899 April 28.752 UT at the standard epoch of April 16.0 and on April 28.754 UT at Zwiers' epoch of September 9.5. With Zwiers' (1902, 1905) improved two-apparition solution (1892-1900) as the reference, the perihelion-time prediction based on Kohlschütter's orbit requires ΔT of −0.154 day and is therefore more accurate than Zwiers' (1899a) upgraded prediction, requiring ΔT of +0.434 day.

Comparison with the 1892-1893 orbital sets is favorable to the JPL orbit, as the predicted perihelion time comes out approximately midway between Zwiers' (1895a, 1897) and Kohlschütter's (1896a, 1896b) definitive orbits. The perihelion-time prediction for 1899, based on the JPL orbit, is off by only 0.01 day from the perihelion time indicated by Zwiers' (1902, 1905) two-apparition solution (Table 2). Integrating this orbit by Zwiers back to 1892 offers for the perihelion time June 14.023 UT at the standard epoch of 1892 July 1.0, June 13.948 UT at Zwiers' epoch of November 4.5, and June 13.909 UT at Kohlschütter's epoch in December. Comparison shows that the JPL orbit agrees by far the best, to 0.028 day, with this 1892 perihelion time, while all 1892 entries in Table 2 differ from it by more than 0.05 day. Thus, in terms of the perihelion time, the JPL orbit fits very well the available one- and two-apparition solutions based on the astrometric observations from 1892-1900.

These considerations lead one to a peculiar effect that is apparent from Table 2 between the JPL orbit on the one hand and the three-apparition, 1892-1906, gravitational runs by Koebcke (1948) and by Williams (1999) on the other hand. The latter solutions yield a perihelion time systematically earlier in 1892, are in agreement with the JPL orbit in 1899, and show the comet to be at perihelion later in 1906. By contrast, Zwiers' (1906c) three-apparition gravitational solution places the comet at perihelion in 1906 earlier than the JPL orbit. This may, at least in part, be due to the fact that Zwiers (1912a) felt that Wolf's (1907) last observation in 1906 — badly off especially in right ascension — "cannot be said to have improved matters" and preferred to use only the first three observations from 1906 (Zwiers 1906c). On the other hand, Koebcke (1948) retained the last 1906 observation in his equations, despite a residual of nearly $10''$ in right ascension.

This analysis shows that the gravitational orbital solutions linking the three apparitions between 1892 and 1906 are less crucial than the one-apparition and two-apparition solutions and carry less weight in testing the JPL orbit, as their perihelion times at the apparitions at both ends of the linked arc may be affected by systematic errors due to neglect of nongravitational effects. However, the accuracy of these three-apparition solutions is much better at the middle, 1899 apparition. Table 2 illustrates that the JPL orbit is in very good agreement with both Williams' (1999) and Koebcke's (1948) perihelion times in 1899. Zwiers' (1906c) three-apparition solution is inferior, leaving large discrepancies in the perihelion times.

In summary, comparison with the various gravitational solutions from the period 1892-1906 leads to a conclusion that the accuracy of the perihelion-time prediction offered by the JPL orbit is always quite satisfactory, well within the uncertainties of observation. Also, the agreement of the JPL orbit with the nongravitational solutions by Marsden (2004, 2005) and by Kinoshita (2009) between 1964 and 2007 is excellent, the three sets always agreeing to better than 0.004 day. The JPL and Kinoshita's sets differ by a maximum of 0.064 day in 1892. Using the 1892 and 1899 perihelion times from Zwiers' (1902, 1905) improved two-apparition solution as primary criteria, acknowledging in particular that for near-perihelion epochs the 1892 perihelion time was apparently very close to June 14.00 UT, and also noting that Kohlschütter's (1896a, 1896b) one-apparition orbit is better than either of the two by Zwiers (1895a, 1897), I suggest that the JPL orbit should be preferred to Kinoshita's.

This conclusion justifies taking the JPL orbit as a reference standard to grade the sets of predicted elements available to search for 17P at the returns following 1906. After the 1913-1920 debacle (Sec. 3), the quality of orbital predictions improved, as seen from Table 2. For the 1928 return, Polak's (1928) ephemeris was fairly good, but the prediction for the 1935 return by Foxell and McNeile (1934) was less satisfactory. Although Foxell and McNeile applied the perturbations by Jupiter and Saturn from 1928 on, their work was based on the results for the 1928 return by Cripps (1927), who applied only Jupiter's perturbations from 1913 on and whose prediction was inferior to Polak's (1928). Polak's (1949, 1950) subsequent predictions, a belated one for 1942 and a timely one for 1950, in turn used Foxell and McNeile's (1934) elements to compute the perturbations by Jupiter from 1935 on. The quality of Polak's (1949) orbital set for 1942 was worse than the 1928 and 1935 predictions, but his prediction for 1950 was slightly better than for 1942 (Table 2). This was apparently the last effort to provide a search ephemeris before Marsden (1963) took over.

5. Likelihood of Major Explosions During Missed Returns of Comet 17P/Holmes

Because seven consecutive returns of comet 17P to the sun went unnoticed, it would be rather difficult to answer the question of whether an additional super-massive explosion was missed between 1892-1893 and 2007, without first contemplating three important pieces of evidence of observational nature that affect the degree of likelihood of detecting such an event. First, the circumstances at discovery in 1892 suggest that it is practically impossible to miss a comet of apparent visual magnitude 5 that is far enough from the Sun in the sky. Indeed, comet 17P had at least three independent discoverers — E. Holmes, T. D. Anderson, and J. E. Davidson. Although it is possible that the comet's relative proximity to the M31 nebula in the sky helped the discovery to some extent, there are many stationary objects all over the sky that are equally popular with amateur astronomers. Significantly, Holmes and Anderson never discovered any other comet, while Davidson found C/1889 O1 as a naked-eye object. None of the three was a comet hunter. Thus, the discovery of 17P was clearly fortuitous and motivated by the comet's naked-eye visibility.

Second, analysis in Paper 1 of the 1892-1893 and 2007 events provides information on the comet's naked-eye or easy-binocular detection. During its first apparition, the comet was observed as a naked-eye object from the time of discovery on 1892 November 6 (146 days after perihelion; Holmes 1892) until December 11 (181 days a.p.; Backhouse 1902), with binoculars until 1893 January 10 (211 days a.p.; Backhouse 1902); and then again with the naked eye from January 16 (217 days a.p.; Kobold 1893) until at least January 20 (221 days a.p.; Lovett 1893), with binoculars until February 10 (242 days a.p.; Backhouse 1902). In 2007, the comet was a naked-eye object from October 24 (173 days a.p.; *e.g.*, Hale and Yoshida 2007) for several months. Naked-eye magnitudes were still reported by as many as 10 observers after 2008 February 4 (276 days a.p.; *e.g.*, Green 2008a, 2009); the last naked-eye sighting was from March 10 (311 days a.p.; Green 2008a), the last binocular sighting from April 30 (362 days a.p.; Green 2008a), when the comet was only 43° from the sun.

And, third, an overview of the light curve of comet 17P in Paper 2 shows a major, persistent lingering effect of a super-massive explosion over two revolutions about the sun (Sec. 8.1). Intrinsically, the comet was much brighter (at least after perihelion, when under observation) in 1899 and 1906, the two apparitions following the 1892-1893 explosion, than in 1986,[5] 1993, and 2000, each of which followed an uneventful apparition (Sec. 8.1). Likewise, compared with the 1986-2000 apparitions, the comet was fully four magnitudes brighter in late 2008 and early 2009, when receding from the sun following the megaburst.

In an effort to spell out a simple condition for detecting a super-massive explosion of comet 17P based on the two known events, I apply three guiding rules to define the search period: (i) making it as short as possible; (ii) extending it to cover both episodes of the 19th century event and the megaburst of 2007; and (iii) minimizing effects of inferior observing conditions near the time of full moon. From information on the first dates of the comet's naked-eye visibility, the search period is a union of three post-perihelion intervals, each extending over a lunar month: 146-176 days, 173-203 days, and 216-246 days. Truncating to the least multiple of 10-day post-perihelion windows, the search period used below becomes a 90-day long interval from 150 to 240 days after perihelion. Favorable observing conditions are then denied only when the comet is in this critical time near conjunction with the sun.

When comet 17P undergoes a major explosion, its apparent magnitude reaches a peak a few days after the event's onset and then remains essentially constant for a limited period of time. The peak brightness of the 2007 megaburst was reached on October 25.9 UT (174.4 days after perihelion.; Paper 2) and there was no measurable drop in the comet's light curve for some 10 days, until November 4.8 UT (184.3 days a.p.; Paper 2). In the next eight weeks (until the end of December 2007, or ~240 days a.p.), the apparent brightness dropped by slightly more than 1 magnitude, at a very slow rate, averaging some 0.02 magnitude per day. In the subsequent 14 weeks (until early April 2008, or ~340 days a.p.), the apparent brightness dropped another 2 magnitudes, at about the same average rate. For the 1892-1893 explosion the rate of fading after each episode was apparently more rapid, but the published data are too inaccurate to say by how much.

The apparent magnitude $H_{\rm app}(t)$ at time t after the peak has been reached is given by

$$H_{\rm app}(t) = (H_0)_{\rm peak} + \Delta H(t) + \Delta H_0(t), \tag{1}$$

where $(H_0)_{\rm peak}$ is the peak intrinsic magnitude (Sec. 1),

$$\Delta H(t) = 5 \log[\Delta(t)\, r(t)], \tag{2}$$

with $\Delta(t)$ and $r(t)$ being, respectively, the geocentric and heliocentric distances (in AU) of the comet at time t, and $\Delta H_0(t) \geq 0$ is a change (decrease) in the intrinsic brightness between the peak and time t. The total rate of brightness decrease is given by the rate of change in the sum of $\Delta H + \Delta H_0$. In addition, there is a small phase effect, which can be incorporated into ΔH_0. The ephemeris shows that between the peak and 240 days after perihelion, the rate of change in ΔH was about 0.01 magnitude per day, or 50 percent of the total, so that in this time span $\Delta H \approx \Delta H_0$. In the subsequent 14 weeks (until 340 days after perihelion), the change in ΔH predicted from the ephemeris is 1.6 magnitudes,

[5] There are only two magnitude estimates available from the apparition of 1986 (Paper 1), about 90 and 290 days after perihelion, but nothing unusual in the comet's appearance was reported on the images taken by the Spacewatch project for astrometry over a period from 197 to 230 days after perihelion (Gehrels and Scotti 1986; Scotti 1987).

giving an average rate of 0.016 magnitude per day. Thus, between 240 and 340 days after perihelion, the total rate of brightness decrease was dominated by ΔH, with the decrease in the intrinsic brightness, ΔH_0, amounting to only 0.4 magnitude, or $\frac{1}{4}$ of ΔH.

The peak intrinsic magnitude is a constant for each particular event: $(H_0)_{\rm peak} = -0.53$ for the megaburst of 2007 (Paper 2), while $(H_0)_{\rm peak} = +1.9$ and $+1.2$ for the two episodes in 1892-1893 (Paper 1) or $+0.74$ for their summed up (composite) intrinsic magnitude. Unlike temporal variations in ΔH, changes in ΔH_0 cannot be predicted. They depend on a number of dust particles leaving the comet's halo as a function of time and on possible large-scale particle fragmentation, which should affect the distribution of cross-sectional areas of fragment grains relative to their parent grains and the particle scattering efficiency.

A naked-eye (or binocular) detection is characterized by a limiting apparent magnitude $H_{\rm lim}$, which, when inserted into Eq. (1) indicates that

$$\Delta H(t) < H_{\rm lim} - (H_0)_{\rm peak} - \Delta H_0(t). \tag{3}$$

Under favorable observing conditions, a deliberate naked-eye search is described by $H_{\rm lim} \simeq 6$. With $\Delta H_0 \approx 0$, this constraint gives

$$\Delta H < 6.5 \text{ mag} \tag{4}$$

in the case of the megaburst of 2007, and

$$\Delta H < 4.1 \text{ mag} \tag{5}$$

for the worst-case scenario — the first episode of the 19th-century explosion — when searching not too long after the peak. For a deliberate binocular search, the constant on the right-hand side of (3) is greater by, say, 3 magnitudes ($H_{\rm lim} \simeq 9$). Thus, a binocular detection requires $\Delta H \lesssim 7$; if ΔH_0 is increased by as much as 2 magnitudes, then in the worst case $\Delta H \lesssim 5$.

This discussion can be summarized into four points:

(1•) *A major explosion makes comet 17P a naked-eye object for some — and an easy binocular object for most or all — of the time between 150 and 240 days after perihelion.*

(2•) *Once comet 17P becomes a naked-eye (easy-binocular) object it cannot (can hardly) remain undetected unless under persistently inferior observing conditions.*

(3•) *It is argued that, for the missed returns, the naked-eye detections should be contingent upon conforming to a rule-of-thumb condition $\Delta H \lesssim 4$ mag; the binocular detections, to a condition $\Delta H \lesssim 7$ mag.*

(4•) *A major explosion has a lingering effect over apparently two succeeding revolutions about the sun, during which comet 17P remains intrinsically much brighter than in the course of ordinary, "quiescent" returns.*

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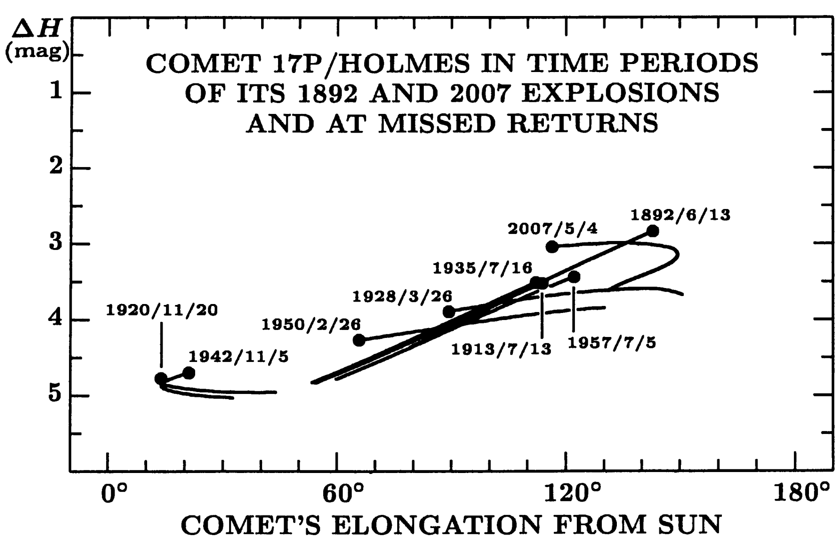

Figure 1. A plot of ΔH vs. elongation of 17P from the sun. The seven missed returns, 1913-1957, are compared with the apparitions during which the comet was observed to explode, 1892 and 2007. For each return, the bullet, identified by the computed perihelion date, refers to a time 150 days after perihelion. The other end of each orbital arc depicts the comet's location at a time 240 days after perihelion. In terms of observing conditions, the best returns are 2007, 1928, and 1892, while the worst are 1920 and 1942.

Having the sets of high-quality orbital elements available from Table 1, it is now straightforward to generate a tool needed to investigate a degree of likelihood of a super-massive explosion of 17P being overlooked during the missed returns. This tool is a plot, for each missed return, of ΔH from Eq. (2) as a function of the sun's elongation during the time span between 150 and 240 days after perihelion. The results of this exercise are presented in Figure 1, where the missed returns are compared with the apparitions of 1892 and 2007.

The figure provides important information. While until 1906 the comet's orbital period was slightly less than 7 years, a close approach to Jupiter in December 1908 caused it to increase to almost exactly $7\frac{1}{3}$ years, so that the comet-sun-earth geometry at the returns between 1913 and 1964 was repeated every 22 years or 3 revolutions about the sun. As a result of another approach to Jupiter in April 1968, this pattern was broken as the period decreased to slightly more than 7 years. The 22-year cycle divides the missed returns between 1913 and 1957 into three categories: in 1913, 1935, and 1957 the best observing conditions were at the beginning of the 90-day-long arc, or 150 days after perihelion; in 1928 and 1950 the conditions were gradually improving with time and were the best at the end of the arc, or 240 days after perihelion; and in 1920 and 1942 they were about equally unfavorable, the comet always less than $\sim$45° from the sun along the entire critical arc of the orbit. The 1928 return competes with the 1892 and 2007 apparitions in terms of the most favorable observing conditions.

Figure 1 shows that the returns of 1913, 1928, 1935, 1950, and 1957 were favorable in that a major explosion between 150 and 240 days after perihelion would always have occurred at a large enough elongation from the sun, between $\sim$60° and $\sim$150°, with the whole critical arc of the orbit in Figure 1 above the line $\Delta H = 5$ and more than a half of it above $\Delta H = 4.1$, thus largely satisfying conditions 1•, 2•, and 3• for naked-eye detection. In the light of the 1892 discovery facts, it is extremely unlikely that a similar major explosion during any of these five returns would remain unreported. Only at the returns of 1920 and 1942, when the comet was very close to the sun in the sky during the entire critical period of time and with ΔH near 5 magnitudes, a major explosion of 17P may have remained undetected.

The differences between the missed returns 1920 and 1942 on the one hand and the rest on the other hand are clearly apparent from a limited ephemeris of the comet presented in Table 3. It is noted that regardless of the month the perihelion takes place, during the critical period of time the comet was always in the first quadrant and high in the north. To obtain diagnostic data on the degree of likelihood of a super-massive explosion in 1920 or 1942, one has to employ condition 4• and secure information on the succeeding returns. Since, fortunately, searches were conducted in both 1928 and 1950 (Sec. 3), they are examined — and the reasons for their failure discussed — separately below.

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Table 3. Limited ephemeris (eq. J2000.0) for comet 17P/Holmes at missed returns 1913–1957 and predicted apparent magnitudes for an assumed major-explosion scenario.[a]

Date of perihelion passage (ET)	Time after perihelion											
	150 days			180 days			210 days			240 days		
	R.A.	Dec.	$H_{\rm app}$	R.A.	Dec.	$H_{\rm app}$	R.A.	Dec.	$H_{\rm app}$	R.A.	Dec.	$H_{\rm app}$
1913 July 13	$0^{\rm h}18^{\rm m}.0$	+27°34′	5.5	$0^{\rm h}47^{\rm m}.4$	+27°41′	6.0	$1^{\rm h}29^{\rm m}.7$	+29°19′	6.5	$2^{\rm h}19^{\rm m}.6$	+31°40′	6.8
1920 Nov. 20	1 50.5	+25 15	6.8	2 48.5	+30 38	6.9	3 47.2	+35 00	7.0	4 44.3	+38 16	7.0
1928 Mar. 26	3 37.2	+39 33	5.9	3 58.0	+44 57	5.7	3 49.8	+48 45	5.6	3 18.0	+48 50	5.7
1935 July 16	0 17.4	+27 23	5.5	0 48.3	+27 40	6.0	1 31.6	+29 23	6.5	2 22.3	+31 48	6.8
1942 Nov. 5	1 34.2	+24 05	6.7	2 32.5	+29 29	6.9	3 32.2	+33 54	7.0	4 31.3	+37 10	7.0
1950 Feb. 26	3 27.5	+35 43	6.3	4 10.0	+40 58	6.1	4 36.4	+45 38	6.0	4 35.2	+49 17	5.9
1957 July 5	0 20.0	+28 57	5.4	0 42.9	+28 15	5.9	1 21.1	+29 16	6.4	2 08.4	+31 17	6.8

[a] Calculated with $(H_0)_{\rm peak} + \Delta H_0 = +2.0$ mag. In a major explosion comparable to the megaburst of 2007, the comet would be brighter than tabulated by up to 2.5 magnitudes; on the other hand, weeks after a major explosion comparable to the January 1893 outburst, the comet could easily be fainter by 2 magnitudes or more.

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6. Astrometric Assessment of Search for Comet 17P in 1928

Interested in recovering comet 17P in 1928, Van Biesbroeck copied, in his short reports on comets, a part of Cripps' (1927) ephemeris that he had obtained from A. C. D. Crommelin for a pre-perihelion period of time (Van Biesbroeck 1927a) and a part of Polak's (1928) ephemeris for a post-perihelion period (Van Biesbroeck 1928b). Because of its southern declinations in late 1927, Van Biesbroeck (1928a) did not search for the comet until September 1928, some 6 months after perihelion (Sec. 3). Details on the four photographic observations that he secured are, based on information from his observing book, presented in Table 4. The most important piece of astrometric data is in column 9, which indicates that Polak's ephemeris was in error by no more than 0°.3; the distance from the line of variation was only about 4′. Since the plates used by Van Biesbroeck with the 60-cm Yerkes reflector were 75 mm by 100 mm in size, covering a field of 1°.8 by 2°.4, the comet's position was undoubtedly exposed fairly close to the middle point on all four exposures centered on Polak's ephemeris places.

Table 4. Van Biesbroeck's 1928 search exposures of comet 17P/Holmes and an ephemeris (eq. J2000.0).

Time of observation (1928 UT)	Plate No.	Time after perihelion (days)	Exp. time (min)	Ephemeris position[a]		Difference JPL−Polak			Distance (AU)	
				R.A.	Dec.	in R.A.	in Dec.	total	Earth	Sun
Sept. 16.30602	2925	174.06624	36	$3^{h}55^{m}.86$	$+43^{\circ}57'.8$	$-1^{m}.44$	$+2'.1$	$15'.7$	2.1529	2.6216
16.33310	2926	174.09332	36	3 55.88	+43 58.1	−1.43	+2.2	15.6	2.1527	2.6217
25.13813	2932	182.92543	35	3 58.58	+45 25.1	−1.62	+1.3	17.1	2.0855	2.6473
25.16521	2933	182.95251	35	3 58.58	+45 25.3	−1.62	+1.3	17.1	2.0853	2.6474

[a] From the JPL orbit.

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Since one cannot expect that an observer as experienced as Van Biesbroeck could possibly overlook the comet's images on four different plates, the only possible conclusion is that the comet was too faint to show up even on the long exposures. This problem is addressed in connection with the comet's light curve in Sec. 8.2.

7. Astrometric Assessment of Search for Comet 17P in 1950

Van Biesbroeck gave up on comet 17P after 1928, as his observing book shows no record of exposures for this object in 1935, when the conditions were only slightly less favorable than in 1928 (Figure 1). However, Martynov's unsuccessful search based on Polak's (1950) new ephemeris provides useful constraints. While I am unaware of any report by Martynov himself about his negative results, the two references mentioned in Sec. 3 complement each other. A limiting magnitude 15 (with no information on the dates, exposure times, type of emulsion, etc.) was published by Editors (1950) in a short report issued on September 28, 1950, whereas Merton (1951) noted that Martynov's search took place in September and October 1950 and that the Engelhardt Observatory's 38-cm $f/2.4$ Schmidt camera was used to sweep an area of the sky several degrees in extent and covering Polak's (1950) prediction.

Since the reports are incomplete and inaccurate, additional information was obtained from Martynov's (1951; see Sec. 3) paper on the Engelhardt's Observatory's 38-cm Schmidt telescope, but the dates and emulsion must be guessed. One can expect that the search was made near the dates of the new moon in September and October 1950, which are used as approximations in Table 5. And since Martynov (1951) indicated that the Agfa Astro plates were heavily employed at the time, it is assumed that, unfiltered, they were used to search for 17P and that therefore the limiting magnitude 15 refers to a "blue sensitive" photometric system. Polak's (1950) prediction was off by a little more than 2°, which places the comet well inside the photographed field centered on the ephemeris position and near the boundary of the vignetting-free field, with practically no downgrading of the comet's image; the search was also assisted by acceptably small distances from the line of variation, 2′ in September and 11′ in October.

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Table 5. Martynov's 1950 search for comet 17P/Holmes and an ephemeris (eq. J2000.0).

Date of new moon[a] (0^{h} ET)	Time after perihelion (days)	Ephemeris position[b]		Difference JPL−Polak			Distance (AU)	
		R.A.	Dec.	in R.A.	in Dec.	total	Earth	Sun
1950 Sept. 12	197.9	$4^{h}28^{m}.5$	$+43^{\circ}50'$	$-11^{m}.7$	$-8'$	$2^{\circ}.11$	2.388	2.694
Oct. 11	226.9	4 39.7	+47 54	−14.0	+9	2.35	2.160	2.786

[a] Martynov's unknown search times assumed to be near the date of new moon.
[b] From the JPL orbit.

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Thus, as in the case of the 1928 search, it is concluded that comet 17P was not detected by Martynov on the 1950 Schmidt plates because of its intrinsic faintness, an issue that is deferred to Sec. 8.3.

8. Light Curve of Comet 17P and Its Brightness at Search Times

The goal is now to determine how the limiting magnitudes of the 1928 and 1950 searches fare relative to the comet's light curve at the quiescent-phase apparitions, like 1986-2000, on the one hand, and at the apparitions with a strongly elevated brightness, like 1899-1906, on the other hand. To address this objective, one needs to uniformly calibrate and streamline the photometric systems of the apparitions investigated in Papers 1 and 2 and to examine the remaining apparitions 1964-1979, for which only "nuclear" magnitudes are available. Since only the 1920 and 1942 missed returns are in question as far as a potential occurrence of super-massive explosions is concerned, and since the searches were made during the immediately succeeding returns of, respectively, 1928 and 1950, the potential excess brightness is best simulated by the 1899 light curve, after its proper calibration. The "nuclear" magnitudes from the 1972 and 1979 apparitions are helpful for assessing the degree of likelihood of a major explosion at the apparition of 1964, during which the comet was not favorably located in the sky when between 150 and 240 days after perihelion.

8.1. Calibration of the Light Curves of Comet 17P at Individual Apparitions

Starting with the 2007 apparition of comet 17P/Holmes, I describe the light curve as a plot of time t, reckoned from the comet's perihelion passage, against the total visual magnitude $H_\Delta(t)$, estimated with an average naked eye and normalized to a distance $\Delta = 1$ AU from the earth by a Δ^{-2} law; this scale was extended to faint magnitudes by linking post-megaburst naked-eye observations with CCD observations made by an observer with the same instrumentation both before and after the event. An observer with an average eye was defined by sampling 52 participants, who reported their naked-eye magnitude estimates to the *International Comet Quarterly* and whose data were incorporated into the final 2007 light curve of comet 17P presented in Paper 2; for 17 of these 52 observers — including R. J. Bouma, E. van Dijk, D. W. E. Green, A. Hale, K. Hornoch, M. Meyer, A. Pereira, and S. Yoshida — the applied correction was less than ± 0.1 magnitude (*i.e.*, each of them overestimated or underestimated the brightness, on the average, by less than 10 percent relative to the mean of the whole sample), while the extreme corrections of -0.65 and $+0.35$ magnitude were derived to apply to the naked-eye estimates by, respectively, K. Sarneczky, who underestimated the brightness, on the average, by 45 percent, and T. Scarmato, who overestimated it by 38 percent, relative to the mean of the 52 observers.

Since the light curves for the apparitions 1986-2000 were linked in Papers 1 and 2 to the photometric scale established for the apparition 2007, they have already been calibrated as accurately as they could be. The light curve for 1892-1893, reduced in Paper 2 to the photometric scale of Barnard's naked-eye magnitudes summarized by Bobrovnikoff (1943), is not used in this paper. It should suffice to say that the photometric systems of 1892-1893 and 1986-2007 probably agree with each other to about $\frac{1}{2}$ magnitude.

The mean light curve for the apparition of 1899 was in Paper 2 referred to a magnitude scale of Perrine (1899, 1900a), who made his visual observations with the 91-cm refractor of the Lick Observatory and reported the comet to be, in an overlapping period of time, about 1 magnitude brighter than estimated by Barnard, who used the 102-cm refractor of the Yerkes Observatory.[6] An objective of Paper 2 — to show that comet 17P was intrinsically brighter in 1899 than in 1986-2000 — has been met even if Perrine did not underestimate the comet's total brightness. With Perrine's magnitudes uncorrected, the comet was found to be 1.7 magnitudes intrinsically brighter in 1899 than in 1986-2000 when more than 150 days after perihelion. In late 2008 and early 2009, long after the megaburst, the comet was intrinsically about 4 magnitudes brighter, as indicated by an extrapolated 1986-2000 light curve in Figure 1 of Paper 2.

A more challenging goal, converting the 1899 light curve to the photometric system of the 1986-2007 light curves, requires that an aperture correction be determined to Perrine's estimates with the 91-cm refractor. The only plausible approach is to combine the difference between Perrine's[7] and Barnard's estimates with the finding by Marcus (1983) that Barnard's magnitudes of comets obtained with the large refractor at Yerkes referred almost always to the nuclear condensation and required at least a $-2\frac{1}{2}$ magnitude correction to be reduced to Bobrovnikoff's (1941) standard telescopic aperture of 6.8 cm.[8] Since Bobrovnikoff's formula implies a correction of -0.066 magnitude per 1 cm of aperture for

[6] Barnard never published any details on his visual brightness estimates of comets beyond occasional vague references to a nuclear condensation. A very helpful paper was published by Marcus (1983), who compares Barnard's 28 brightness estimates of 16 comets with 37 magnitudes, reported for times that were within three days of Barnard's times, by other observers using much smaller telescopes. Marcus emphasizes that Barnard's estimates were "not made in reference to stars of known magnitude", as no photometric catalogues of such faint stars were then available, but points out that this is not a serious drawback if one tries to establish only an approximate *empirical* correction. Bobrovnikoff (1948) — also quoted by Marcus — perceived Barnard's magnitudes as "simple impressions of the total brightness" and suggested that one may assume a degree of internal consistency of Barnard's magnitudes on the strength of the observer's reputation. One could toy with an idea that Barnard (and possibly other visual comet observers working with large refractors in the late 19th and early 20th centuries) may have devised and used unpublished photometric scales based on their experience with observing faint nebulae, to have at least some photometric tools, but this is a mere speculation, as no references (except by J. Holetschek for brighter nebulae and star clusters) to any such data are found in the literature. Obviously, the old visual magnitudes of comets, especially those obtained with large refractors, cannot be judged in terms of modern brightness estimates and the only, however approximate, way to handle these old data is by applying a large magnitude-scale correction, usually referred to as an "aperture" correction. Marcus (1983) pointedly remarks that old-style observation methods are primarily to blame for such large corrections. For Barnard's magnitudes obtained with the 102-cm refractor at Yerkes, Marcus derives from his collected data a correction of at least -2.5 magnitudes, while Bobrovnikoff (1948) finds from Barnard's estimates of comet 14P/Wolf on 28 nights in 1918-1919 a correction of -3.2 magnitudes, both referred to Bobrovnikoff's (1941) standard telescopic aperture of 6.8 cm.

[7] Like with Barnard, the methodology of Perrine's magnitude estimating is unknown. Published, as a rule, to a precision to 0.5 magnitude, major systematic differences between the brightness estimates by the two observers can largely be removed by applying a relative correction based on the data from overlapping time intervals. This relative correction is then combined with a correction for a selected "standard" observer (in this case Barnard) that relates his magnitude scale to the adopted photometric system of an average "naked eye" (see the beginning of this subsection), acquired or estimated from independent evidence (provided by Marcus 1983 in this case), to obtain a final correction for each observer. Because details of the observing techniques are unavailable, no more sophisticated approach can be applied.

[8] A magnitude-scale correction depends not only on the aparture of the telescope but also on its f-ratio, magnification used, etc. The apparent over-emphasis on the aperture has to do with the fact that the methodology for finding an appropriate correction, proposed by Bobrovnikoff (1941), uses only the aperture diameter as a parameter, neglecting the other factors.

smaller refracting instruments, the reduction of Barnard's magnitudes to the photometric system used in this paper requires an additional aperture correction of −0.4 magnitude, from 6.8 cm to the naked eye. This exercise suggests that a *conservative* aperture correction for Barnard's extimates made with the large Yerkes refractor in reference to our photometric system is −3 magnitudes, implying a correction of −2 magnitudes for Perrine with the large Lick refractor.

My effort to derive Perrine's aperture correction for the 91-cm refractor more directly met with very little success. Perrine's career as a comet observer at Lick was relatively short-lived and his observations with the large refractor were limited to very faint comets and not always accompanied by magnitude estimates. Although Perrine became a Lick staff member in 1893, he used the large refractor more extensively only after Barnard's 1895 departure, and even then brighter comets, for which magnitude data obtained with much smaller instruments elsewhere (*e.g.*, by J. Holetschek in Vienna) are available for comparison, were observed by Perrine mostly with a 30-cm refractor. By 1903 his scientific interests changed and none of his later Lick-based papers dealt with comets. By the time Halley's comet appeared, Perrine left Lick for Argentina, where he became director of the National Observatory at Córdoba. The only comet for which Perrine's (1900b) observations with the 91-cm refractor and Holetschek's (1900) magnitudes obtained with a 16-cm refractor overlap is 10P/Tempel in July 1899, and even then it is possible that Perrine's total-brightness estimate (magnitude 9) was made with the refractor's finder. It seems that Perrine may have underestimated the total and/or "nuclear" magnitude of 10P by a fraction of a magnitude relative to Holetschek, whose estimates require an aperture correction of −1 magnitude in the least.

Adopting Perrine's aperture correction as −2 magnitudes, I find that the 1899 calibrated light curve of 17P/Holmes, when more than 150 days after perihelion, becomes 3.7 magnitudes brighter than in 1986-2000 and can quite satisfactorily be linked with the comet's light curve based on the data reported in late 2008 and early 2009, a year and more following the megaburst.

The magnitude estimates of comet 17P from the four plates taken in 1906 at the Königstuhl Observatory near Heidelberg are the only brightness data available from this apparition, and they are very difficult to calibrate. Although all reported by Wolf (1906a, 1906b, 1906c, 1906d, 1906e, 1907) in identical format, the first three observations were made with the 41-cm $f/5$ Bruce twin refractor, one of them by A. Kopff, while the last observation was made by Wolf with the 72-cm $f/4$ Waltz reflector.[9] I have shown in Paper 2 that in the relevant period of time, between 150 and 300 days after perihelion, the uncorrected 1906 light curve practically coincides with Perrine's (1899, 1900a) uncorrected magnitudes from 1899. Direct comparison of Wolf's and Perrine's magnitude systems is not possible, because the instrument used by Wolf before 1900, when Perrine made most of his comet observations, was a 16-cm $f/5.1$ Voigtländer camera. The

[9] Inspection of Wolf's early publications shows that he expended considerable effort on providing as accurate magnitudes of asteroids and comets from his plates as he could. His method focused on three tasks: (i) a determination of photographic magnitudes for stars by measuring and calibrating the apparent diameters of their photographic images and including effects of exposure time (Wolf 1890) [he also applied this technique to find a limiting magnitude on plates as a function of exposure time (Wolf 1892a)]; (ii) a relationship between magnitudes of stars derived photographically and by means of visual photometry (Wolf 1891); and (iii) a determination of magnitudes for comparison stars from plates with sidereal tracking and an estimation of magnitudes of minor planets and comets from plates with tracking on these moving objects (Wolf 1892b, 1892c). A detailed review of Wolf's method would require a study of its own. In this brief evaluation, it should be emphasized that he was both familiar with, and contributed to, the state-of-the-art investigations in the field of photometry of celestial objects in general and their photographic photometry in particular. In one of his key papers (Wolf 1891), he described in detail the employed method, using stars in a cluster GC 4410 as an example, by comparing meticulously measured diameters of photographed stars in the Pleiades with the previous results of Charlier (1889) and Scheiner (1889, 1890, 1891), who in turn investigated the correlation between the photographically determined magnitudes of stars in this cluster and their magnitudes derived by visual photometry (Pickering 1882; Lindemann 1887; see also Pritchard 1882), with the effects of color, atmospheric extinction, and exposure time incorporated in the discussion of the findings. Wolf's (1891) comparison table shows that his magnitudes for 28 stars in the Pleiades cluster, brighter than magnitude 11, are in excellent agreement with the photographic magnitudes by Charlier (1889) and the visual magnitudes by Pickering (1882). The mean difference Wolf minus Charlier is $+0.01 \pm 0.17$, while the mean difference Wolf minus Pickering is $+0.17 \pm 0.22$, possibly showing a color effect. Wolf (1891) also found that the magnitude scale of the Bonner Durchmusterung was inferior, making the stars of magnitude 9.5 and fainter much too bright, by up to 1 magnitude or even more. Wolf (1891) detected the same problem when comparing his magnitudes for the stars in GC 4410 with those from the Bonner Durchmusterung, rejecting the latter and concluding that with appropriate telescopes it was possible to determine magnitudes with fair accuracy, except that atmospheric extinction affected the quality of the determination at low elevations. The error also increased for fainter objects, but this problem could be mitigated by taking plates of various exposure times and deriving the magnitudes from overlapping diameter-magnitude plots. Because this method was instrument dependent, Wolf obviously had to repeat these procedures with every newly acquired telescope. Although he did not always report the results, the fact that he attended to this task in the same consistent manner (using the Pleiades) is apparent from his publication of the dependence of the limiting magnitudes on the exposure time for the Voigtländer camera and the Bruce refractor (Wolf 1910a), the instruments that had been unavailable in 1891. Also, as more reliable photometry became gradually available for stars fainter than magnitude 11, Wolf was apparently extending his photometric scale. This is evident from this same paper on the limiting magnitudes, in which he said that an 80-minute exposure with the Bruce telescope reached magnitude 16, based on a "very large number of observations". However, I was unable to find any comment by Wolf on his method of accounting for extended dimensions of comets, although he is known to have focused on observing very faint (and small) comets for which a point-like approximation was not entirely unreasonable and whose brightness he never estimated to a precision higher than 0.5 magnitude. Yet, it is certain that Wolf's comet magnitude determinations did not refer to the truly *total brightness* and that their quality was inferior to the quality of brightness estimates obtained by modern methods. These differences — as well as the effects of color, zero point of the photometric system used, etc. — are hoped in this paper to be approximately accounted for by applying a constant magnitude-scale correction.

first of the two Bruce twin telescopes was not completed until 1899 and the Waltz reflector not until 1906.[10]

Wolf's (1900c) conclusion that faint comets are very rarely detected photographically (see the footnote) seems to have been at the root of his apparent reluctance to observe comets in general. The most prolific discoverer of minor planets in his time, Wolf often titled his reports as "photographic observations of minor planets and comets" but hardly ever did he list more than a single comet with dozens of minor planets. This explains why my thorough search for Barnard's (1932a, 1932b, 1932c, 1932d) near-simultaneous observations of comets between 1898 and 1922 produced only two positive correlations with Wolf. One was 33P/Daniel (1909 IV = 1909e), photographed by Wolf (1910b) on 1910 December 15 at magnitude 11.0 and observed visually by Barnard (1932a) with the 102-cm refractor on December 7 at magnitude 11 and 12 days later at magnitude 12. The other was 4P/Faye (1910 V = 1910e), photographed by Wolf (1911a, 1911b) on 1911 March 19 and 23 at magnitude 15 and 14.5, respectively, and observed visually by Barnard (1932b) on March 20 at magnitude 14.5. Wolf did not specify the telescopes used, but Voigtländer exposure times would have had to be near or more than two hours in the case of 4P. Apparently striving for a uniform, instrument-independent magnitude system, Wolf's tendency was to rely increasingly on the 72-cm reflector. The comparisons show that, on the average, Wolf's magnitudes were slightly, perhaps by up to 0.5 magnitude, brighter than Barnard's visual magnitudes with the 102-cm refractor. From this information, Wolf's aperture correction to the naked-eye photometric system becomes −2.5 magnitudes or slightly higher and the near-coincidence of the 1899 and 1906 light curves, suggested in Paper 2, remains valid.

My search for nearly simultaneous observations also revealed two instances suitable for comparing the magnitudes reported by Wolf and by Van Biesbroeck.[11] While insufficient for establishing a correction, this is of interest in connection with Van Biesbroeck's (1928a) search for comet 17P in 1928 (Sec. 8.2). The first instance was 22P/Kopff (1926 II = 1926c), recovered photographically by Wolf (Strömgren 1926) on 1926 July 13 at magnitude 16 and observed photographically by Van Biesbroeck (1927b) with the 60-cm Yerkes reflector on July 16 at magnitude 17. The second was C/1930 E1 (Beyer; O.S. 1930 IV = 1930b), which was photographed by Wolf (1931) with the 72-cm Waltz reflector on 1931 June 15 and 16 at magnitude 16.5 and by Van Biesbroeck (1933) with the 60-cm Yerkes reflector on June 15 at magnitude 16. These comparisons show that Wolf's and Van Biesbroeck's photometric scales were similar, at least in the range of magnitudes 16-17.

The next step in investigating the light curve of comet 17P involves the three apparitions during which only "nuclear" magnitudes were reported — 1964, 1972, and 1979. At the first two returns, the comet was observed only by Roemer, at Flagstaff in 1964 and 1965 (Roemer and Lloyd 1966) and at Catalina and Kitt Peak in 1971-1973 (Roemer 1971a,

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[10] Before comparing Wolf's magnitudes from plates taken with the Bruce telescope with Barnard's visual magnitudes estimated with the 102-cm refractor at Yerkes, I mention a peculiar case of comet 17P photographed by Wolf in *1899* (sic). This is generally unknown and, to my knowledge, has never been mentioned in any review papers or other documents describing a chronology of discoveries, recoveries, and observations of comets in 1899, not even in comprehensive summaries, such as those by Kreutz (1900a, 1900b, 1902). Yet, acknowledging that at its 1899 apparition comet 17P was allegedly observed with only the world's most powerful telescopes, at Yerkes and at Lick, Wolf (1900a) revealed in his observatory report for 1899 that the object was photographed at Königstuhl with the Voigtländer camera on August 14 and again on 1899 October 8-9, and that *its positions were measured*. This announcement is corroborated by two additional remarks. In a report on a photographic observation of comet C/1900 B1 (Giacobini; O.S. 1900 I = 1900a) from 1900 February 21, Wolf (1900b) stated explicitly that this comet's brightness, which he estimated at magnitude 12, was between the brightness of comet 17P, observed "here in August and October", and that of comet 8P/Tuttle "at the time of its discovery", which in an earlier telegraphic note was estimated at magnitude 11.5 (Wolf 1899). One can therefore guess that comet 17P was magnitude ~12.5, presumably in August 1899, when, according to Barnard (1932a), it was about 2 magnitudes brighter than in October. Since Barnard estimated, with the 102-cm refractor, comet 17P to be magnitude 13 on August 15, and $13\frac{1}{2}$ on August 16, the reconstructed estimate by Wolf on the Voigtländer August plate is 0.5 to 1 magnitude brighter than Barnard's. The second remark on the detection of 17P at Königstuhl in 1899 comes from Wolf's (1900c) short paper on his unsuccessful search for comet D/1892 T1 (Barnard; 1892 V = 1892e), expected to return during 1899 but lost until very recently (the comet has now been designated 206P/Barnard-Boattini; cf. Boattini 2008, and Green 2008b, 2008c). Wolf listed 26 searched fields photographed with the Voigtländer camera, covering a total projected area between 1200 and 1500 square degrees. He emphasized that except for 17P no other comet-like object was detected, which he felt showed how infrequently faint comets are found photographically. With the exposure times ranging mostly between 1.5 and 4 hours, the limiting magnitude (Wolf 1910a) must have been ~14.4 or fainter. The fields reportedly showing comet 17P had exposure times of 116 to 120 minutes, implying a limiting magnitude near 14.8. Thus, the guessed August magnitude of 12.5 was easily within the range, and the October brightness, if 2 magnitudes fainter, would still be slightly above the detection threshold. In addition, 16 Persei, the loadstar of Wolf's August 14 exposure was only 2°.4 from the ephemeris position of 17P on that date, while the field covered by the plate had an effective diameter of ~8°. All these findings appear to point to Wolf's detection of comet 17P in 1899 (on August 14, in the least) and to a magnitude correction of −2 to −2.5 magnitudes for Voigtländer plates, slightly higher than the correction to Perrine's visual magnitudes with the large Lick refractor. Yet, no astrometric results have ever been published, in spite of Wolf's (1900a) claim that the images were measured, and the detection of comet 17P/Holmes at the Königstuhl Observatory in 1899 remains problematic.

[11] After his arrival at the Yerkes Observatory in 1915, Van Biesbroeck observed comets mostly with the 30-cm refractor, but by 1917 the shares of his observations with the 30-cm and the 102-cm refractors were already about equal. In a report of his measurements of comet 2P/Encke in 1924 (Van Biesbroeck 1925), he provided limited information on his method of estimating the brightness. The presented set consists of visual magnitude estimates with the 102-cm refractor (2 data points) and the refractor's 10-cm finder (7 points), and of photographic magnitude estimates (2 points) with then the relatively new 60-cm reflector (see footnote 2). Van Biesbroeck stated that all his brightness estimates of comets were obtained extrafocally, with an out-of-focus eye-piece, so that the comet and the comparison stars were nearly equal in size, and that the brightness of the comparison stars was on the Harvard scale. Unfortunately, he did not describe the method of determination of the magnitudes obtained photographically, nor did he address the question of correcting the photometric scale of the visual estimates taken with the large refractor. Luckily, a formula for Van Biesbroeck's aperture correction has been derived from another evidence (Sec. 8.2).

1971b, 1972a, 1972b, 1973a, 1973b); at the third return, "nuclear" magnitudes were reported by Shao and Schwartz (1979) at Oak Ridge and by Seki (1979) at Geisei. All these observations were photographic, and blue-sensitive plates were probably always employed.[12] It is assumed that these magnitudes H_{pg} are on the International System ($H_{pg} = P$), and the task is to convert them to visual magnitudes, H_v. This is done by equating

$$H_v = H_{pg} + (H_v - V) - (P - V), \tag{6}$$

where V is a standard Johnson-system V magnitude that corresponds to a visual magnitude H_v. Various conversion formulas from $(P - V)$ to $(B - V)$ of the Johnson system were given by a number of authors. Kron and Mayall (1960) concluded that their color index $(P - V)$, closely approximating the International System, satisfies a relation $(P - V) = (B - V) - 0.10$ with a precision to ± 0.03 at $-0.4 \leq (P - V) \leq +1.0$. Discussing the difference between H_v and V, Green (1997) refers to Howarth and Bailey's (1980) simple conversion formula

$$H_v = V + 0.16\,(B - V), \tag{7}$$

in which case the difference $H_v - H_{pg}$ is a function of the color index $(B - V)$ alone. Inspection of Snodgrass *et al.*'s (2008) large set of graphically presented B, V, R, and I photometry of 17P, obtained a few days after the megaburst, shows that $(B - V)$ averaged between +0.7 and +0.8. Comparison of this V, R, and I photometry with that before the megaburst (Snodgrass *et al.* 2006) suggests that the indices $(V - R)$ and $(R - I)$ did not change after the megaburst in any significant way. Thus, assuming $(B - V) \simeq +0.75$, one finds $H_v = V + 0.12$ and, finally,

$$H_v = H_{pg} - 0.53. \tag{8}$$

The "nuclear" magnitudes from the 1964, 1972, and 1979 apparitions, converted this way to the visual magnitudes and normalized not only to a unit geocentric distance but also to a zero phase angle β by applying a correction -0.035β (about -0.6 magnitude on the average), are presented in Figure 2. Its inspection shows that only the earliest pre-perihelion "nuclear" magnitudes at the apparitions of 1964 (~120 days before perihelion) and 1972 (~220 days) are fairly close to the nucleus' predicted true (pre-megaburst) magnitudes (see the caption for the references). Along the post-perihelion orbital branch, the "nuclear" magnitudes from 1964-1979 are consistently between the light curves of the nucleus and of the whole comet in 1986-2000, but they are much closer to the latter. No such conclusion is possible for the pre-perihelion branch because of the lack of data on the total brightness. No significant increase in the "nuclear" brightness is apparent from 1964 to 1972 and 1979 to support a hypothesis of a major explosion of 17P between 150 and 240 days after the 1964 perihelion. If such a major explosion had occurred, the comet could have become a binocular object from mid-September 1965 on, 300+ days after perihelion, when more than 80° from the sun.

While the discussion of one objective of this section, a calibration of the "nuclear" magnitudes from 1964-1979, offers no surprising results, the findings relevant to the other objective, a calibration of the light curves from 1899 and 1906, imply, in a plausible generalization, that during the two returns to the sun that immediately follow the return with a super-massive explosion, the comet is intrinsically brighter, relative to the quiescent-phase returns, by about 3.5 to 4 magnitudes along much of the post-perihelion branch of the orbit (except possibly shortly after perihelion), and may, in addition, undergo relatively minor outbursts, like the one in 1899, detected and presented in Paper 2.

The relation between the light curves in 1899 and 1906 has not as yet been completely resolved, although it is fair to say that they nearly coincide in the interval between about 150 and 300 days after perihelion, the calibration uncertainties in Wolf's magnitudes notwithstanding. A piece of evidence that at first sight appears to contradict this tentative conclusion is based on Aitken's (1900, 1907) reports on comet 17P, which he observed in 1899 but failed to detect in 1906 with the same instrument, the 91-cm Lick refractor. In 1899, Aitken estimated the comet to be, in general, fainter than magnitude 14 during his observing run, between 105 and 135 days after perihelion, along the subsiding branch of the outburst. In 1906 he unsuccessfully searched for the comet several times between ~150 and ~190 days after perihelion, concluding that it was fainter than magnitude 15 (Sec. 3). Aitken's reports from the two apparitions thus suggest that in 1906 the comet was during his search at least ~1 magnitude fainter. From the 1899-1906 calibrated light curve in Figure 2 (and Paper 2), an apparent total visual brightness during Aitken's 1899 observations never dropped below magnitude ~11.5, while in 1906 it stayed near magnitude 13, if the intrinsic brightness varied identically with time from perihelion. This is consistent with Aitken's reports, if his aperture correction with the 91-cm refractor is about -3 magnitudes or more, which is significantly higher than Perrine's correction. Thus, the 1899 and 1906 light curves could indeed have been equally elevated relative to the light curve in a quiescent phase.

The apparent persistence of elevated brightness during the returns to the Sun that follow a super-massive explosion of 17P (point 4• in Sec. 5) is of great importance for interpreting search results, because the time constraint inherent to a major explosion does not apply to the light curve in the succeeding returns; thus: *a significantly elevated intrinsic*

[12] To the best of my knowledge, with a possible exception of Martynov, the observers that photographed comet 17P between 1906 and 1979 (Wolf, Van Biesbroeck, Roemer, Shao and Schwartz, and Seki) were all tracking the comet properly, so that there was no loss of brightness because of failure to account for the comet's apparent motion. All these observers used the comet's images to provide astrometric positions of good to high quality, which they could not with sidereal tracking during long exposures. There is every indication that — with a possible exception of Van Biesbroeck — they also took separate plates with sidereal tracking to obtain sharp images of comparison stars. For Martynov's 1950 search the question of proper vs. sidereal tracking is unimportant, because the system used was a very fast Schmidt camera (Martynov 1951), which allowed short exposures (on the order of 1 minute) to obtain deep images and had a small plate scale (> 200″ per mm), implying practically no loss in surface brightness, especially for a slowly moving comet like 17P.

brightness along most of the post-perihelion branch of the orbit becomes diagnostic of a major explosion one or two revolutions earlier.[13] The searches in 1928 and 1950 were conducted at times between 150 and 240 days after perihelion anyway, but the relaxed time constraint allows one to conclude that the comet's 1972-1979 post-perihelion "nuclear" brightness data, which stay consistently below the average 1986-2000 light curve in Figure 2, provide evidence against a major explosion during the preceding returns 1957-1964. Since nothing is known about the comet's total brightness on approach to the Sun, the difference in the pre-perihelion "nuclear" magnitudes between 1964 and 1972 in Figure 2 is left unexplained, except for a note that the perihelion distance then dropped from 2.347 to 2.155 AU (Table 1).

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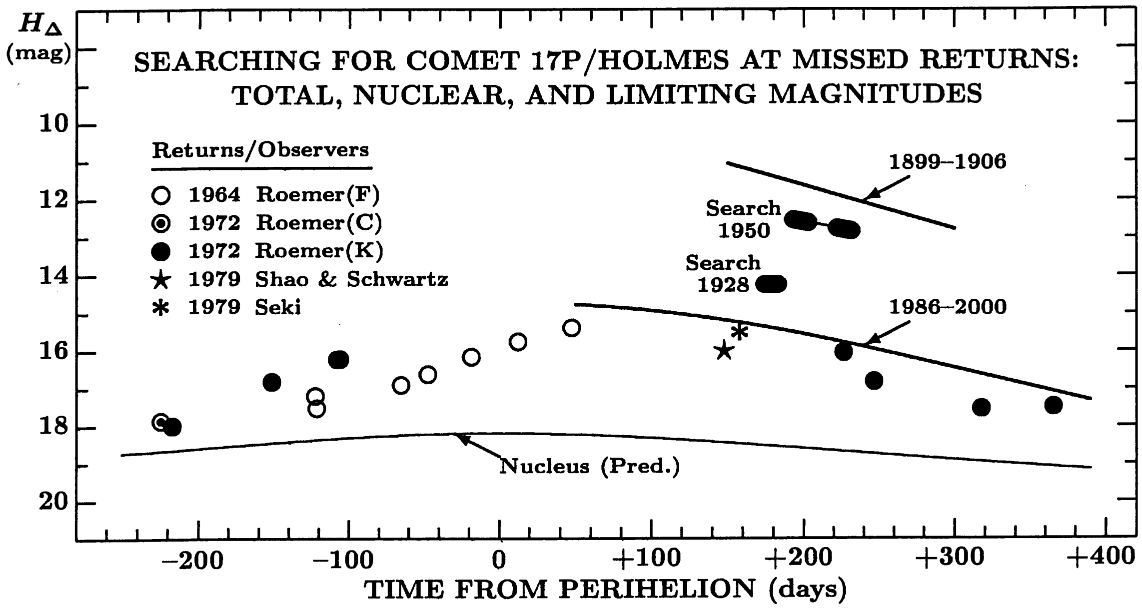

Figure 2. Light curves of comet 17P/Holmes and the circumstances during the searches in 1928 and 1950. The time from perihelion is plotted against the total visual magnitude H_Δ normalized to 1 AU from the Earth. Fitted by the thick curves are the variations in the total visual magnitude at the apparitions 1899 and 1906 (from 150 to 300 days after perihelion) and at the apparitions 1986, 1993, and 2000 (from 50 to 390 days after perihelion). Depicted by the thin curve is the predicted visual magnitude of the nucleus (from 250 days before perihelion to 390 days after perihelion) at a zero phase angle and an assumed geometric albedo 0.04, based on the results by Lamy et al. (2000) and by Snodgrass et al. (2006). The various symbols refer to the normalized and phase-effect-corrected "nuclear" magnitudes obtained photographically by Roemer with the 102-cm f/6.8 Ritchey-Chrètien reflector at the Flagstaff Station (F) of the U.S. Naval Observatory during the 1964 apparition and with the 154-cm f/13.5 Cassegrain reflector at the Catalina Station (C) of the Lunar and Planetary Laboratory, University of Arizona, and the 229-cm f/9 Ritchey-Chrétien reflector of the Steward Observatory at Kitt Peak (K) during the 1972 apparition; and by Shao and Schwartz with the 155-cm Wyeth reflector of the Harvard-Smithsonian Center for Astrophysics at the Oak Ridge Observatory, Harvard, Mass., and by Seki with a 60-cm f/3.5 reflector at the Geisei Observatory, Kochi, Japan, during the 1979 apparition. The elongated spots show the locations on the plot of the unsuccessful searches in 1928 and 1950, indicating that in either case the comet would have been detected if a super-massive explosion occurred in, respectively, 1920 and 1942.

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I have no firm answer to the question of an activity level of 17P, relative to a quiescent phase, at the returns three (or possibly more) revolutions after a major explosion. However, I pointed out in Paper 1 that following the 1995 outburst of comet 73P/Schwassmann-Wachmann, coinciding with a series of fragmentation events, it took two revolutions about the sun, or nearly 11 years, before the comet's principal component "calmed down" to the activity level of the parent prior to the outburst. The peak intrinsic magnitude of that outburst was $(H_0)_{\rm peak} = 5.3$ (Paper 1), indicating an amount of dust in the atmosphere that is less than 5 percent of the minimum amount of dust following a super-massive explosion.

One can speculate about the chances of 17P having been discovered as a new comet during the ill-fated 1913 return (with the predicted perihelion time off by 6 months), three revolutions after the 1892-1893 super-massive explosion, if the light curve continued to be elevated by as much as 4 magnitudes above a quiescent phase. In this scenario, the comet would have been an object of total visual magnitude 12 during November 1913 at an elongation of ~130° from the sun and near magnitude 11 in early October, near the opposition.

[13] Minor outbursts have a relatively short duration (several weeks at the most), so that the occurrence of such an event at a given return cannot be confused with the long-term effects of a super-massive explosion during a previous return.

To examine the chances of accidental detection, I compiled, from Kronk's (2007) cometography, a list of comets discovered, independently of an ephemeris, in the years 1910-1916. They are arranged in Table 6 in the order of increasing brightness at the time of discovery. Unfortunately, no magnitude at discovery was reported for nine comets, and these had to be excluded from the table. However, they were mostly brighter objects, some detected with the naked eye, but a few were reported, days after discovery, to be as faint as magnitude 9-10. None of them would end up near the top of Table 6.

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Table 6. Discovery magnitudes of comets from the years 1910–1916.

Comet[a]	Discovery time (UT)	Magnitude	Mode	Discoverer and observing site
C/1916 G1	1916 Apr. 4.01	13.0	phot.	M. Wolf (Königstuhl, Germany)
24P/1911 X1	1911 Dec. 1.20	12.0	vis.	A. Schaumasse (Nice, France)
C/1914 M1	1914 June 24.90	12.0	phot.	G. N. Neujmin (Simeis, Crimea, Russia)
8P	1912 Oct. 19.19	11.5	vis.	A. Schaumasse (Nice, France)
C/1913 Y1	1913 Dec. 18.04	11	vis.	P. T. Delavan (La Plata, Argentina)
25D/1916 D1	1916 Feb. 24.78	11	phot.	G. N. Neujmin (Simeis, Crimea, Russia)
C/1912 V1	1912 Nov. 2.80	10.0	vis.	A. Borrelly (Marseilles, France)
28P/1913 R2	1913 Sept. 3.98	10.0	phot.	G. N. Neujmin (Simeis, Crimea, Russia)
21P/1913 U1	1913 Oct. 23.80	10	vis.	E. Zinner (Bamberg, Germany)
4P	1910 Nov. 8.90	9.5	phot.	V. Cerulli (Teramo, Italy)
C/1913 J1	1913 May 7.11	9.5	vis.	A. Schaumasse (Nice, France)
C/1914 F1	1914 Mar. 30.07	9.5	vis.	H. H. Kritzinger (Bothkamp, Germany)
C/1910 P1	1910 Aug. 9.14	8	vis.	J. H. Metcalf (Taunton, Mass., U.S.A.)
C/1911 S2	1911 Sept. 23.84	7.5	vis.	F. Quénisset (Juvisy, France)
20D/1913 S1	1913 Sept. 27.1	7	vis.	P. T. Delavan (La Plata, Argentina)
C/1914 J1	1914 May 15.9	4	vis.	V. Zlatinsky (Mitava, Latvia, Russia)
C/1911 S3	1911 Sept. 29.12	3	vis.	S. I. Beljawsky (Simeis, Crimea, Russia)

[a] Not listed are periodic comets recovered with the help of an ephemeris, and comets for which no magnitude was reported by the discoverer for the discovery date; the latter include: C/1911 N1 (Kiess), C/1911 O1 (Brooks), C/1912 R1 (Gale), C/1913 R1 (Metcalf), C/1914 S1 (Campbell), C/1915 C1 (Mellish), C/1915 R1 (Mellish), and 10P and 69P in 1915.

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It appears from the table that, nominally, observers in the 1910s were capable of discovering, especially photographically, comets as faint as 17P would have been if it were intrinsically brighter by 4 magnitudes than in a quiescent phase. However, there are two caveats: (i) the magnitudes listed in Table 6 are as reported by discoverers, with unknown accuracy and no corrections to the total visual magnitude applied; and (ii) because of an increase in perihelion distance between the returns of 1906 and 1913, the comet, even with its brightness elevated, may have been a few tenths of a magnitude fainter compared to 1899-1906. Although no firm conclusion can be reached from the fact that 17P was not re-discovered in 1913, the best guess — supported by analogy to comet 73P described above — is that, by the time comet 17P began its third revolution about the sun following the super-massive explosion, it was likely to have faded enough not to exceed *significantly* its brightness in a quiescent phase.

8.2. Limiting Normalized Magnitude on the 1928 Yerkes Search Plates

Since Van Biesbroeck (1928a and observing book) did not provide a limiting magnitude in his unsuccessful search for comet 17P in September 1928, it is necessary to estimate it as closely as possible from his photographic observations with the 60-cm Yerkes reflector. With the exposure time always recorded by Van Biesbroeck, his observations of other comets around 1928 can — on a plot of reported magnitudes against exposure times — be used to provide information on the limiting magnitude $H_{\rm lim}$. For this purpose I collected a total of 46 observations, whose exposure times $\tau_{\rm exp}$ exceeded 15 minutes and which referred to 11 comets photographed in the years 1926-1930 (Van Biesbroeck 1927b, 1928c, 1930). The comets included 8 periodic ones (2P, 7P, 15P, 21P, 22P, 26P, 29P, and 37P) and three in nearly-parabolic orbits (C/1925 F1, C/1925 F2, and C/1927 E1). The longest exposure time was 80 minutes. Van Biesbroeck's observed magnitudes $H_{\rm obs}$ are expected to correlate with the exposure times, because fainter comets need longer exposures. Figure 3 confirms this trend and shows that the correlation is consistent with the photographic reciprocity law between the intensity (brightness) $I_{\rm obs}$ and the exposure time, $I_{\rm obs} \cdot \tau_{\rm exp} = {\rm const}$. The law in Figure 3 is conservative, based on a presumption that a comet at magnitude 17.5 on a 30-minute exposure is just barely above the detection limit. The limiting magnitude is then

$$H_{\rm lim} = 14.0 + 2.5 \log \tau_{\rm exp}, \qquad (9)$$

where the exposure time is in minutes. For the 35- and 36-minute exposures of comet 17P (Table 4), the limiting magnitudes in Van Biesbroeck's photometric system are essentially the same, near 17.9.

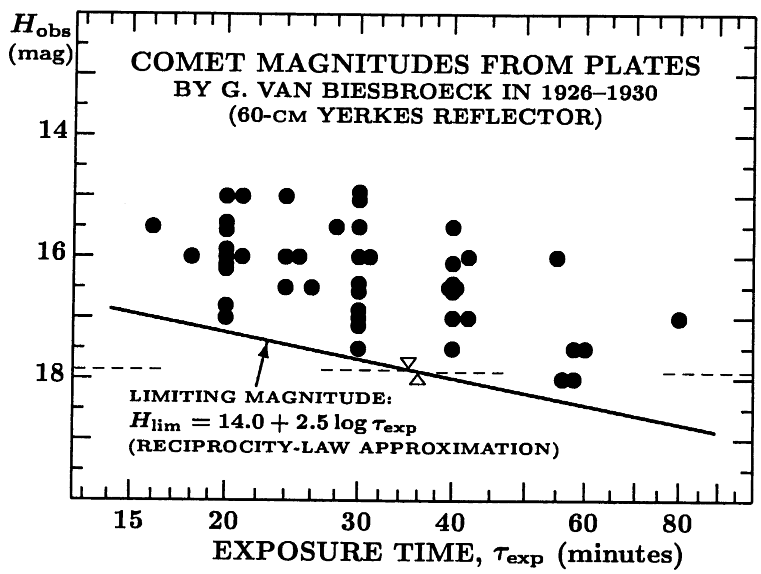

Figure 3. A plot of observed magnitude H_{obs} against exposure time τ_{exp}, based on 46 photographic observations of eleven comets by Van Biesbroeck (1927b, 1928c, 1930) made with the 60-cm Yerkes reflector in 1926-1930. Not included are comets observed low above the horizon, since they do not contribute to the determination of a limiting magnitude H_{lim}. The line for H_{lim} is a photographic reciprocity law approximation, corresponding, conservatively, to a limiting magnitude 14 reached with an exposure time of 1 minute. The triangles pointing up and down are showing, respectively, the limiting magnitudes for the plates in Van Biesbroeck's search for comet 17P taken on 1928 Sept. 16 (36-minute exposure) and 1928 Sept. 25 (35-minute exposure).

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Next, these magnitudes need to be converted to equivalent total visual magnitudes in the system used in this paper. This is important because Van Biesbroeck's magnitudes of faint comets refer to little more than a nuclear condensation, so in terms of the total visual magnitude, Van Biesbroeck's limiting magnitudes are not as faint as Eq. (9) indicates. The conversion is achieved in a manner similar to that used to determine Barnard's and Wolf's magnitude scales in Sec. 8.1, by comparing Van Biesbroeck's magnitudes with brightness estimates by comet observers with known personal/instrumental corrections to the total magnitude. I undertook a comprehensive study of this problem some years ago in connection with my interest in the light curve of comet 2P/Encke. Van Biesbroeck's (1939, 1944, 1949, 1953, 1955, 1958, 1962) brightness estimates of this comet from the apparitions 1937-1961 in the range of magnitudes 6 to 15 were compared with Beyer's (1938, 1950, 1955, 1962) series of uniform visual brightness estimates in an equivalent range of magnitudes 6 to 13, and extrapolated to Van Biesbroeck's magnitudes fainter than 15. Van Biesbroeck's magnitudes of comets were obtained with a variety of instruments: visually with the 102-cm Yerkes refractor and its finder (discontinued in 1943) and with binoculars; photographically with the 60-cm reflector and, starting in 1940, with the 208-cm *f*/3.9 reflector at the McDonald Observatory. Van Biesbroeck strived to make his magnitude system essentially instrument independent, but it suffers from a "Delta" effect (for details on this subject see, *e.g.*, Öpik 1963). During the 1937-1961 apparitions, Encke's comet was observed by Van Biesbroeck with the large refractor only in 1937 and with the 208-cm reflector only in 1951-1957, but with the 60-cm reflector at every apparition except 1954. Thus, the formula converting Van Biesbroeck's magnitude $H_{\rm VB}$ to the total visual magnitude H_v (Sekanina, unpublished) is particularly appropriate for the photographic observations with the 60-cm reflector:

$$H_v = H_{\rm VB} - 0.05 - 0.587\,(H_{\rm VB} - 8.0) + 0.0293\,(H_{\rm VB} - 8.0)^2 + 3.14\,\log\Delta, \tag{10}$$

where Δ is a geocentric distance in AU. Because the coefficient of the linear term $H_{\rm VB} - 8.0$ is negative, it may seem that Van Biesbroeck overestimated the brightness of naked-eye and easy-binocular comets. However, such comets (certainly 2P/Encke) are nearly always at geocentric distances smaller than 1 AU, so the $\log\Delta$ term usually more than compensates for the effect of the linear and quadratic terms. For example, on 1937 November 30, Van Biesbroeck estimated Encke's comet, which was 0.344 AU from the earth, at magnitude 6. The linear and quadratic terms add 1.17 and 0.12 magnitudes, respectively, to the correction, but the $\log\Delta$ term alone subtracts 1.45 magnitudes. The corrected magnitude is 5.79, about 0.2 magnitude brighter than estimated by Van Biesbroeck.

For the limiting magnitudes in Van Biesbroeck's unsuccessful 1928 search for comet 17P, Eq. (10) gives a correction of almost exactly -2.0 magnitudes to obtain the equivalent total visual magnitudes $(H_v)_{\rm lim} \simeq 15.9$ on the exposures from September 16 and 25. From Table 4, the normalized limiting total visual magnitudes $(H_\Delta)_{\rm lim}$ are 14.3 on both dates, with the geocentric distance normalization, the Delta effect, and the differential-exposure effect canceling out. This result, plotted in Figure 2, shows that Van Biesbroeck's exposures were much deeper than needed to easily detect comet 17P if its intrinsic brightness in 1928 was elevated as much, or nearly as much, as in 1899, following the super-massive explosion in 1892-1893. On the other hand, if the comet was essentially in a quiescent phase in 1928, just as it was at the apparitions of 1986-2000, Van Biesbroeck's exposures did not reach deep enough to detect the object. Condition 4• from Sec. 5 implies with virtual certainty that there was no major explosion of comet 17P in 1920 — not even in 1913 (thereby confirming independent evidence from Sec. 5).

8.3. Limiting Normalized Magnitude on the 1950 Kazan Search Photographs

Given the limited data (Editors 1950, Merton 1951) on Martynov's search for 17P in 1950, I interpret the information conveyed in Sec. 7 to mean that comet 17P would have been detected if its total blue-sensitive magnitude were 15 in mid-September or mid-October. The limiting total visual magnitude then requires only a color-index correction (Sec. 8.1), $(H_v)_{\rm lim} = 14.5$, and the normalized limiting total visual magnitude $(H_\Delta)_{\rm lim}$ at the times of the new moon become 12.6 in mid-September and 12.8 in mid-October (Table 5).

The result, plotted in Figure 2, is based on a presumption that in either month the search was conducted during a period of ten days centered on the date of the new moon. Similarly to the 1928 search (Sec. 8.2), Figure 2 shows that, throughout the search period, the limiting brightness remained below the elevated light curve at the returns immediately following the return with a major explosion — this time by more than 0.8 magnitude. Again invoking condition 4•, one concludes, with much confidence, that there was no super-massive explosion of comet 17P/Holmes in 1942 or 1935 (in accord with evidence from Sec. 5), even if one allows for a minor effect due to the increased perihelion distance compared with 1899-1906.

9. Conclusions

From the extensive investigation of the intrinsic brightness and orbital motion of comet 17P/Holmes in 1892-2009, I find that — with a high degree of likelihood — the object experienced no additional super-massive explosion between 150 and 240 days after perihelion comparable to those in the discovery and most-recent apparitions.

The absence of any such major explosion during the observed apparitions is demonstrated conclusively by the comet's light curves in 1899, 1906, 1993, and 2000; by the "nuclear" magnitudes in 1972 and 1979; and by other evidence in 1964 and 1986. A major explosion during the 1964 apparition would have made the comet an easy-binocular object more then 300 days after perihelion at large elongations from the sun. In 1986, nothing unusual in the comet's appearance was reported by the observers of the Spacewatch Project on images taken for astrometry in the period between 197 and 230 days after perihelion. Thus, from 1964 to 2000 the comet was probably continuously in a quiescent phase.

The argument for all but two of the seven missed returns relies on an analogy with the circumstances at the comet's discovery in 1892 and on evidence that the comet becomes a naked-eye object during a fraction, and an easy-binocular object during much or all, of the interval between 150 to 240 days after perihelion as a result of the super-massive event. In the course of the missed returns of 1913, 1928, 1935, 1950, and 1957, the observing conditions during the critical period of time were favorable enough that, if in major explosion, 17P would have been discovered as a new comet.

Evidence of lingering, strongly elevated activity of comet 17P throughout much of the post-perihelion branch of the orbit during the two returns to the Sun (but doubtful in the third) that directly follow the return with a major explosion is employed to practically eliminate chances of such explosions during the remaining two missed returns with unfavorable conditions. Provided by the calibrated light curves from 1899, 1906, and late 2008 and early 2009, this information signals — when compared with the unsuccessful photographic searches conducted in 1928 and 1950 — a high degree of likelihood for no major explosions in 1920 and 1942: the exposures of both searches were deep enough and the limiting magnitudes faint enough for detecting the comet with its lingering, elevated activity but not in a quiescent phase. In summary, recurring of super-massive explosions of comet 17P between 1892 and 2009 on a time scale much shorter than 115 years is effectively ruled out.

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REFERENCES

Aitken, R. G. (1900). "Observations of Holmes's Comet 1899 II", *Astron. Nachr.* **151**, 29-30.
Aitken, R. G. (1907). "Note on Comet Holmes", *Publ. Astron. Soc. Pacific* **19**, 84.
Backhouse, T. W. (1902). "Comet III. 1892 (Holmes)", *Publ. West Hendon House Obs.* **2**, 77-95.
Barnard, E. E. (1932a). "Observations of Comets (I)", *Astron. J.* **41**, 145-152.
Barnard, E. E. (1932b). "Observations of Comets (II)", *Astron. J.* **41**, 153-160.
Barnard, E. E. (1932c). "Observations of Comets (III)", *Astron. J.* **41**, 161-167.
Barnard, E. E. (1932d). "Observations of Comets (IV)", *Astron. J.* **41**, 180-184.
Beyer, M. (1938). "Physische Beobachtungen von Kometen. III", *Astron. Nachr.* **264**, 401-408.
Beyer, M. (1950). "Physische Beobachtungen von Kometen. VII", *Astron. Nachr.* **278**, 217-249.
Beyer, M. (1955). "Physische Beobachtungen von Kometen. IX", *Astron. Nachr.* **282**, 145-167.

Beyer, M. (1962). "Physische Beobachtungen von Kometen. XII", *Astron. Nachr.* **286**, 219-240.

Boattini, A. (2008). "Comet P/2008 T3 (Boattini)", *IAU Circ.* 8993.

Bobrovnikoff, N. T. (1941). "Investigations of the Brightness of Comets, Part I", *Contr. Perkins Obs.* No. 15, pp. 1-139.

Bobrovnikoff, N. T. (1943). "The Periodic Comet Holmes (1892 III)", *Pop. Astron.* **51**, 542-551.

Bobrovnikoff, N. T. (1948). "Periodic Comet Wolf I", *Pop. Astron.* **56**, 130-144.

Charlier, C. V. L. (1889). "Über die Anwendung der Sternphotographie zu Helligkeitsmessungen der Sterne", *Publ. Astron. Ges.* **19**. Leipzig, 32 pp.

Cripps, F. R. (1927). "Holmes, 404", *Handbook Brit. Astron. Assoc. for 1928*, pp. 28-29.

Crommelin, A. C. D. (1920). "Comets", *Mon. Not. Roy. Astron. Soc.* **80**, 406-409.

Crommelin, A. C. D. (1929). "Report on Comets in 1928", *Mon. Not. Roy. Astron. Soc.* **89**, 361-364.

Crommelin, A. C. D. (1936). "Comets", *Mon. Not. Roy. Astron. Soc.* **96**, 344-347.

Ebell, M. (1919). "Holmesscher Komet", *Beob.-Zirk. Astron. Nachr.* **1**, 32.

Ebell, M. (1920). "Holmesscher Komet", *Beob.-Zirk. Astron. Nachr.* **2**, 1.

Editors (1950). "Comets in 1950", *Astron. Circ. USSR* No. 105, pp. 11-12 (in Russian)

Farnsworth, A. H. (1928). "A Comparison of the Photometric Fields of the 6-inch Doublet, 24-inch Reflector, and 40-inch Refractor of the Yerkes Observatory, with Some Investigation of the Astrometric Field of the Reflector", *Publ. Yerkes Obs.* **4** (Pt. 5), 191-227.

Foxell, J. T.; and J. D. McNeile (1934). "Comet Holmes", *Handbook Brit. Astron. Assoc. for 1935*, p. 24.

Gehrels, T.; and J. V. Scotti (1986). "Periodic Comet Holmes", *Minor Plan. Circ.* 11277.

Green, D. W. E., ed. (1997). "Visual Observing", in *Guide to Observing Comets* (Int. Comet Quart. Special Issue; Cambridge, MA, U.S.A.: Smithson. Astrophys. Obs.), Ch. 4, pp. 55-93.

Green, D. W. E. (2008a). "Full-Format Visual Data of Comet 17P", *Int. Comet Quart.* **30**, 81-111; an online list available at URL `http://www.cfa.harvard.edu/icq/icqobs.html`.

Green, D. W. E., ed. (2008b). "Comet P/2008 T3 = 1892 T1 (Barnard-Boattini)", *IAU Circ.* 8995.

Green, D. W. E., ed. (2008c). "Comets 206P/Barnard-Boattini and 207P/NEAT", *IAU Circ.* 9000.

Green, D. W. E. (2009). "Full Tabulated Data: 17P and C/2006 P1", *Int. Comet Quart.* **31**, 28-31.

Hale, A.; and S. Yoshida (2007). "Comet 17P/Holmes", *IAU Circ.* 8886.

Holetschek, J. (1900). "Beobachtungen von Cometen", *Astron. Nachr.* **151**, 299-300.

Holmes, E. (1892). "Discovery of a New Comet in Andromeda", *Observatory* **15**, 441-443.

Howarth, I. D.; and J. Bailey (1980). "Photoelectric and Visual Comparison Star Sequences — II", *J. Brit. Astron. Assoc.* **90**, 265-272.

Kinoshita, K. (2009). "17P/Holmes"; this is an online list of the orbital elements and is available at the following website URL: `http://jcometobs.web.fc2.com/pcmtn/0017p.htm`.

Kobold, H. (1893). "Beobachtungen des Cometen 1892 III (Holmes)", *Astron. Nachr.* **132**, 93-94.

Koebcke, F. (1948). "On the Orbit of Comet Holmes (I Part): Preliminary Researches", *Bull. Soc. Amis Sci. Poznan* (Sér. B: Sci. Math. Nat.) **9**, 47-56.

Kohlschütter, E. (1896a). *Bestimmung der Bahn des Cometen 1892 III (Holmes)*, Inaugural-Dissertation (Kiel: C. Schaidt).

Kohlschütter, E. (1896b). "Definitive Bahnbestimmung des Cometen 1892 III (Holmes)", *Astron. Nachr.* **141**, 241-250.

Kohlschütter, E. (1897). "Bemerkung zu den Bahnbestimmungen des Cometen 1892 III (Holmes)", *Astron. Nachr.* **142**, 401-406.

Kreutz, H. (1899). "Wiederauffindung des Holmes'schen Cometen (1892 III) 1899d", *Astron. Nachr.* **149**, 399-400.

Kreutz, H. (1900a). "Zusammenstellung der Kometen-Erscheinungen des Jahres 1899", *Vierteljahrsschr. Astron. Ges.* **35**, 70-79.

Kreutz, H. (1900b). "Bericht über Kometen", *Vierteljahrsschr. Astron. Ges.* **35**, 354-359.

Kreutz, H. (1902). "Zusammenstellung der Kometen-Erscheinungen des Jahres 1900", *Vierteljahrsschr. Astron. Ges.* **36**, 62-67.

Kron, G. E.; and N. U. Mayall (1960). "Photoelectric Photometry of Galactic and Extragalactic Star Clusters", *Astron. J.* **65**, 581-620.

Kronk, G. W. (2007). *Cometography: A Catalog of Comets*, Vol. 3: 1900-1932 (Cambridge University Press), pp. 179-328.

Lamy, P. L.; I. Toth; H. A. Weaver; C. Delahodde; L. Jorda; and M. F. A'Hearn (2000). "The Nucleus of 13 Short-Period Comets", *Bull. Amer. Astron. Soc.* **32**, 1061 (abstract)

Lindemann, E. (1887). "Die Grösenclassen der Bonner Durchmusterung", *Astron. Nachr.* **118**, 125-128.

Lovett, E. O. (1893). "Filar-Micrometer Observations of Comet f 1892", *Astron. J.* **13**, 27-28.

Marcus, J. N. (1983). "Determination of the 'Aperture Correction' for E. E. Barnard's Visual Comet Magnitudes Estimated in the Yerkes 40-inch Refractor", *Comet News Serv.* No. 83-4, pp. 5-8.

Marsden, B. G. (1963). "On the Orbits of Some Long-Lost Comets", *Astron. J.* **68**, 795-801.

Marsden, B. G. (2004). "Comet 17P/Holmes", *Minor Plan. Circ.* 51822.

Marsden, B. G. (2005). "17P/Holmes", in *Catalogue of Cometary Orbits*, ed. B. G. Marsden and G. V. Williams, 16th edition (Cambridge, MA, U.S.A.: Smithson. Astrophys. Obs.).

Marsden, B. G.; and G. V. Williams (2008). *Catalogue of Cometary Orbits*, 17th edition (Cambridge, MA, U.S.A.: Smithson. Astrophys. Obs.).

Martynov, D. J. (1951). "Anaberrational Schmidt Telescope of the Astronomical Observatory of V. P. Engelhardt", *Izv. Astron. Obs. Engel.* No. 27, pp. 53-75 (in Russian)

Mastrodemos, N. (2009). "JPL Small-Body Database Browser"; this is an online database that is available at the following website URL: `http://ssd.jpl.nasa.gov/sbdb.cgi`.
Merton, G. (1951). "Comets (1950)", *Mon. Not. Roy. Astron. Soc.* **111**, 237-244
Mulherin, J. (2007). "Coma in the Newtonian Telescope"; this is an online article that is available at the following website URL: `http://www.opticalmechanics.com/technical_articles/about_coma.html`.
Öpik, E. J. (1963). "Photometry, Dimensions, and Ablation Rates of Comets", *Irish Astron. J.* **6**, 93-112.
Perrine, C. D. (1899). "Rediscovery and Observation of Holmes's Comet d 1899 = 1892 III", *Astron. J.* **20**, 72.
Perrine, C. D. (1900a). "Observations of Holmes's Periodic Comet 1899 II", *Astron. J.* **20**, 187-188.
Perrine, C. D. (1900b). "Observations of Tempel's Second Comet 1899 IV", *Astron. J.* **20**, 167-168.
Phillips, T. E. R. (1914). "Comets in 1913", *Mon. Not. Roy. Astron. Soc.* **74**, 325-330.
Pickering, E. C. (1882). "The Pleiades", *Astron. Reg.* **20**, 40-43.
Polak, J. (1926). "Über die Bahn des Holmesschen Kometen", *Astron. Nachr.* **228**, 313-316.
Polak, J. (1928). "Neue Elemente und Aufsuchungsephemeride des Holmesschen Kometen", *Astron. Nachr.* **231**, 365-368.
Polak, I. F. (1949). "Motion of Comet Holmes in 1925-1950", *Astron. J. USSR* **26**, 156-159 (in Russian)
Polak, I. F. (1950). "Ephemeris for Comet Holmes in 1950", *Astron. Circ. USSR* No. 100, p. 2 (in Russian)
Porter, J. G. (1941). "Comet Holmes", *Handbook Brit. Astron. Assoc. for 1941*, p. 18.
Porter, J. G. (1958). "Comets (1957)", *Mon. Not. Roy. Astron. Soc.* **118**, 393-400.
Pritchard, C. (1882). "Star Magnitudes", *Astron. Reg.* **20**, 68-69.
Roemer, E. (1964). "Comet Notes", *Publ. Astron. Soc. Pacific* **76**, 358-361.
Roemer, E. (1971a). "Periodic Comet Holmes (1971b)", *IAU Circ.* 2338.
Roemer, E. (1971b). "Comet Notes", *Publ. Astron. Soc. Pacific* **83**, 690-692.
Roemer, E. (1972a). "Comet Notes", *Mercury* **1**, No. 1, 18-19.
Roemer, E. (1972b). "Comet Notes", *Mercury* **1**, No. 6, 18-19.
Roemer, E. (1973a). "Comet Notes", *Mercury* **2**, No. 2, 17-19.
Roemer, E. (1973b). "Comet Notes", *Mercury* **2**, No. 3, 17-19.
Roemer, E.; and R. E. Lloyd (1966). "Observations of Comets, Minor Planets, and Satellites", *Astron. J.* **71**, 443-457.
Scheiner, J. (1889). "Über die Bestimmung der Sterngrössen aus photographischen Aufnahmen", *Astron. Nachr.* **121**, 49-62.
Scheiner, J. (1890). "Über die Bestimmung von Sterngrössen aus photographischen ASufnahmen", *Astron. Nachr.* **124**, 273-278.
Scheiner, J. (1891). "Photographisch-Photometrische Untersuchungen", *Astron. Nachr.* **128**, 113-122.
Schorr, R. (1919). "Holmesscher Komet", *Beob.-Zirk. Astron. Nachr.* **1**, 38.
Schorr, R. (1920). "Holmesscher Komet", *Beob.-Zirk. Astron. Nachr.* **2**, 7.
Scotti, J. V. (1987). "Periodic Comet Holmes", *Minor Plan. Circ.* 11469.
Sekanina, Z. (2007). "Dust Jets, Outbursts, and Fragmentation of Comets", in *Instruments, Methods, and Missions for Astrobiology X*, ed. R. B. Hoover *et al.* (Bellingham, WA, U.S.A.: Int. Soc. Opt. Engin.), *Proc. SPIE* **6694**, pp. I.1-I.15.
Sekanina, Z. (2008a). "On a Forgotten 1836 Explosion from Halley's Comet, Reminiscent of 17P/Holmes' Outbursts", *Int. Comet Quart.* **30**, 63-74.
Sekanina, Z. (2008b). "Exploding Comet 17P/Holmes", *Int. Comet Quart.* **30**, 3-28. (Paper 1.)
Sekanina, Z. (2008c). "Episodic Aging and End States of Comets", in *Instruments, Methods, and Missions for Astrobiology XI*, ed. R. B. Hoover *et al.* (Bellingham, WA, U.S.A.: Int. Soc. Opt. Engin.), *Proc. SPIE* **7097**, pp. X.1-X.15.
Sekanina, Z. (2009). "Comet 17P/Holmes: A Megaburst Survivor", *Int. Comet Quart.* **31**, 5-23. (Paper 2.)
Seki, T. (1979). "Observations Made at the Kochi Observatory, Geisei Station", *Minor Plan. Circ.* 4904.
Shao, C.-Y.; and G. Schwartz (1979). "Periodic Comet Holmes (1979f)", *IAU Circ.* 3384.
Snodgrass, C; S. C. Lowry; and A. Fitzsimmons (2006). "Photometry of Cometary Nuclei: Rotation Rates, Colours and a Comparison with the Kuiper Belt Objects", *Mon. Not. Roy. Astron. Soc.* **373**, 1590-1602.
Snodgrass, C.; A. Fitzsimmons; H. Boehnhardt; and T. Lister (2008). "The October 2007 Outburst of 17P/Holmes", in *Asteroids, Comets, Meteors 2008*, LPI Contr. No. 1405, Paper 8278.
Strömgren, E., ed. (1926). "Periodic Comet Kopff", *IAU Circular* 113.
Van Biesbroeck, G. (1925). "Comet Encke in 1924", *Astron. J.* **36**, 41-43.
Van Biesbroeck, G. (1927a). "Comet Notes", *Pop. Astron.* **35**, 525-527.
Van Biesbroeck, G. (1927b). "Observations of Comets at the Yerkes Observatory", *Astron. J.* **37**, 133-139.
Van Biesbroeck, G. (1928a). "Comet Notes", *Pop. Astron.* **36**, 506.
Van Biesbroeck, G. (1928b). "Comet Notes", *Pop. Astron.* **36**, 444.
Van Biesbroeck, G. (1928c). "Observations of Comets at the Yerkes Observatory", *Astron. J.* **38**, 157-164.
Van Biesbroeck, G. (1930). "Observations of Comets at the Yerkes Observatory", *Astron. J.* **40**, 51-60.
Van Biesbroeck, G. (1933). "Observations of Comets at the Yerkes Observatory", *Astron. J.* **42**, 25-32.
Van Biesbroeck, G. (1935). "Comet Notes", *Pop. Astron.* **43**, 356.
Van Biesbroeck, G. (1939). "Observations of Comets at the Yerkes Observatory", *Astron. J.* **47**, 157-163.
Van Biesbroeck, G. (1944). "Observations of Comets at the Yerkes Observatory", *Astron. J.* **50**, 29-32.
Van Biesbroeck, G. (1949). "Observations of Comets", *Astron. J.* **54**, 81-87.
Van Biesbroeck, G. (1953). "Observations of Comets", *Astron. J.* **58**, 79-87.
Van Biesbroeck, G. (1955). "Observations of Comets", *Astron. J.* **60**, 57-64.
Van Biesbroeck, G. (1958). "Observations of Comets", *Astron. J.* **63**, 296-299.

Van Biesbroeck, G. (1962). "Comet Observations", *Astron. J.* **67**, 422-428.
Williams, G. V. (1999). "17P/Holmes", in *Catalogue of Cometary Orbits*, ed. by B. G. Marsden and G. V. Williams, 13th edition (Cambridge, MA, U.S.A.: Smithson. Astrophys. Obs.).
Wirtz, C. W. (1907). "Beobachtungen von Kometen", *Astron. Nachr.* **174**, 225-232.
Wolf, M. (1890). "Über das Durchmessergesetz bei photographischen Sternaufnahmen", *Astron. Nachr.* **126**, 81-86.
Wolf, M. (1891). "Photographische Messung der Sternhelligkeiten im Sternhaufen G.C. 4410", *Astron. Nachr.* **126**, 297-310.
Wolf, M. (1892a). "Die Anzahl der Sterne auf einigen photographischen Aufnahmen", *Astron. Nachr.* **129**, 321-324.
Wolf, M. (1892b). "Photographische Aufnahmen von kleiner Planeten", *Astron. Nachr.* **129**, 337-342.
Wolf, M. (1892c). "Notiz über photographirte Meteoriten und Cometen", *Astron. Nachr.* **129**, 101-104.
Wolf, M. (1899). "Auffindung des Tuttle'schen Cometen 1899b", *Astron. Nachr.* **148**, 391-392.
Wolf, M. (1900a). "Jahresberichte der Sternwarten für 1899: Heidelberg (Astrophysikalische Abteilung der Grossherzoglichen Sternwarte)", *Vierteljahrsschr. Astron. Ges.* **35**, 121-128.
Wolf, M. (1900b). "Photographische Beobachtung des Cometen 1900a", *Astron. Nachr.* **152**, 63-64.
Wolf, M. (1900c). "Nachsuchung nach Comet 1892 V (Barnard)", *Astron. Nachr.* **151**, 395-396.
Wolf, M. (1906a). "Auffindung des Holmesschen Kometen 1906f", *Astron. Nachr.* **172**, 223-224.
Wolf, M. (1906b). "Photographische Aufnahmen von kleinen Planeten und Kometen", *Astron. Nachr.* **172**, 255-256.
Wolf, M. (1906c). "Photographische Aufnahmen des Holmesschen Kometen und kleiner Planeten", *Astron. Nachr.* **172**, 301-302.
Wolf, M. (1906d). "Photographische Beobachtungen des Holmesschen Kometen", *Astron. Nachr.* **172**, 357-358.
Wolf, M. (1906e). "Photographische Aufnahmen des Holmesschen Kometen und kleiner Planeten", *Astron. Nachr.* **172**, 359-360.
Wolf, M. (1907). "Photographische Beobachtungen von Kometen", *Astron. Nachr.* **173**, 303-304.
Wolf, M. (1910a). "Belichtung und photographierte Größenklasse", *Astron. Nachr.* **185**, 227-228.
Wolf, M. (1910b). "Photographische Aufnahmen von Planeten und des Kometen 1909e (Daniel)", *Astron. Nachr.* **183**, 191-192.
Wolf, M. (1911a). "Photographische Aufnahmen in Königstuhl", *Astron. Nachr.* **187**, 431-432.
Wolf, M. (1911b). "Photographische Aufnahmen in Königstuhl", *Astron. Nachr.* **187**, 463-464.
Wolf, M. (1931). "Photographische Aufnahmen von Kometen und Kleinen Planeten", *Astron. Nachr.* **243**, 367-370.
Zwiers, H. J. (1895a). "Definitive Bahnbestimmung des Cometen 1892 III (Holmes)", *Astron. Nachr.* **138**, 65-78.
Zwiers, H. J. (1895b). "Notices sur les Perturbations de la Comète 1892 III (Holmes)", *Astron. Nachr.* **138**, 419-422.
Zwiers, H. J. (1897). "Nachtrag zur Bahnbestimmung des Cometen 1892 III (Holmes)", *Astron. Nachr.* **142**, 257-264.
Zwiers, H. J. (1899a). "Ephémérides de la Comète de Holmes (1892 III) pour son retour en 1899", *Astron. Nachr.* **149**, 9-14.
Zwiers, H. J. (1899b). "Neue Ephemeride des Holmes'schen Cometen 1899d", *Astron. Nachr.* **150**, 93-96.
Zwiers, H. J. (1899c). "Suite des Ephémérides de la Comète de Holmes 1899 II (1899d)", *Astron. Nachr.* **150**, 341-344.
Zwiers, H. J. (1900). "Ephéméride de la Comète de Holmes 1899 II pour 1900", *Astron. Nachr.* **151**, 157-160.
Zwiers, H. J. (1902). *Recherches sur l'Orbite de la Comète Périodique de Holmes et sur les Perturbations de Son Mouvement Elliptique. II*, (Leyden: E. J. Brill), 108 pp.
Zwiers, H. J. (1905). "Researches on the Orbit of the Periodic Comet Holmes and on the Perturbations of Its Elliptic Motion. III", *Proc. Konink. Nederl. Akad. Weten.* **8**, 642-653.
Zwiers, H. J. (1906a). "Ephemeride des Holmesschen Kometen", *Astron. Nachr.* **170**, 113-114.
Zwiers, H. J. (1906b). "Rückkehr des Holmesschen Kometen in 1906", *Astron. Nachr.* **171**, 65-72.
Zwiers, H. J. (1906c). "Researches on the Orbit of the Periodic Comet Holmes and on the Perturbations of Its Elliptic Motion. IV", *Proc. Konink. Nederl. Akad. Weten.* **9**, 414-424.
Zwiers, H. J. (1907). "Ephemeride des Holmesschen Kometen 1906f", *Astron. Nachr.* **173**, 303-304.
Zwiers, H. J. (1912a). "Researches on the Orbit of the Periodic Comet Holmes and on the Perturbations of Its Elliptic Motion. V", *Proc. Konink. Nederl. Akad. Weten.* **15**, 192-200.
Zwiers, H. J. (1912b). "Wiederkehr des Holmesschen Kometen im Jahre 1912", *Astron. Nachr.* **191**, 437-440.
Zwiers, H. J. (1912c). "Ephemeride des Holmesschen Kometen", *Astron. Nachr.* **192**, 171-172.

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Tabulation of Comet Observations

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 22P/Kopff* ⟹ 2009 Apr. 18.36 and 19.22: moonlight [AMO01]. Apr. 19.11: twilight; comet at alt. 9° [BOU].

◇ *Comet 26P/Grigg-Skjellerup* ⟹ 2008 July 28.01: see comments for comet 77P on 2009 Mar. 21.95 [MAR02].