1989SoPh..122..319C

WAS THE ECLIPSE COMET OF 1893 A DISCONNECTED CORONAL MASS EJECTION?

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(Received 11 October, 1988; in revised form 30 January, 1989)

Abstract. A re-evaluation of observations of the 16 April, 1893 solar eclipse suggests that the 'comet' photographed during totality was, in fact, a disconnected coronal mass ejection. Like the disconnection event in 1980 reported by Illing and Hundhausen, the outward speed of the convex (toward the Sun) surface for the 1893 event was relatively low (~ 90 km s^{-1}). Candidate disconnection events were also observed during solar eclipses in 1860 and 1980.

1. Introduction

Disconnected coronal mass ejections are of interest because they can be interpreted as evidence for magnetic reconnection on the Sun. In a popular model (e.g., Kopp and Pneuman, 1976; Pneuman, 1980; Anzer and Pneuman, 1982), distended magnetic fields, associated with an eruptive prominence, reconnect or 'pinch off' to form a set of low-lying post-flare loops and an upward-propagating, disconnected, magnetic bubble. Illing and Hundhausen (1983) have discussed a possible observation of one such disconnected transient. For the 15–16 March, 1980 event imaged by the SMM coronagraph/polarimeter, they report the outward passage of an 'inverted arch' followed by the 'necking down' of coronal transient material into a narrow ray. Illing and Hundhausen note that there are seven additional candidate disconnection events in the 1980 SMM data set of 68 events.

In this paper we re-evaluate – in the light of current knowledge about coronal mass ejections (CMEs) and, particularly, disconnection events – the observations of a 'comet' (Figure 1(a)) photographed by J. M. Schaeberle during totality of the 16 April, 1893 solar eclipse. This comet bears an interesting resemblance to the disconnection event reported by Illing and Hundhausen (Figure 1(b)). The motivation for this study is three-fold. First, disconnected transients are an expected consequence of magnetic reconnection models of solar flares and ejecta; thus, observations of disconnected mass ejections lend support to the basic reconnection paradigm. Second, examination of additional disconnection events may give some insights into why these events are not observed more frequently. Third, the observation of a mass ejection during a solar eclipse offers a rare opportunity to examine a transient's morphology down to the low corona because of the minimal ($\sim 1\ R_\odot$) occulting disk of the Moon.

In Section 2 we re-evaluate the 'eclipse comet of 1893' and argue that this feature was, in fact, a disconnected mass ejection and in Section 3 we briefly note two other candidate disconnection events that were observed during solar eclipses. In Section 4 we summarize the observations and discuss their possible significance.

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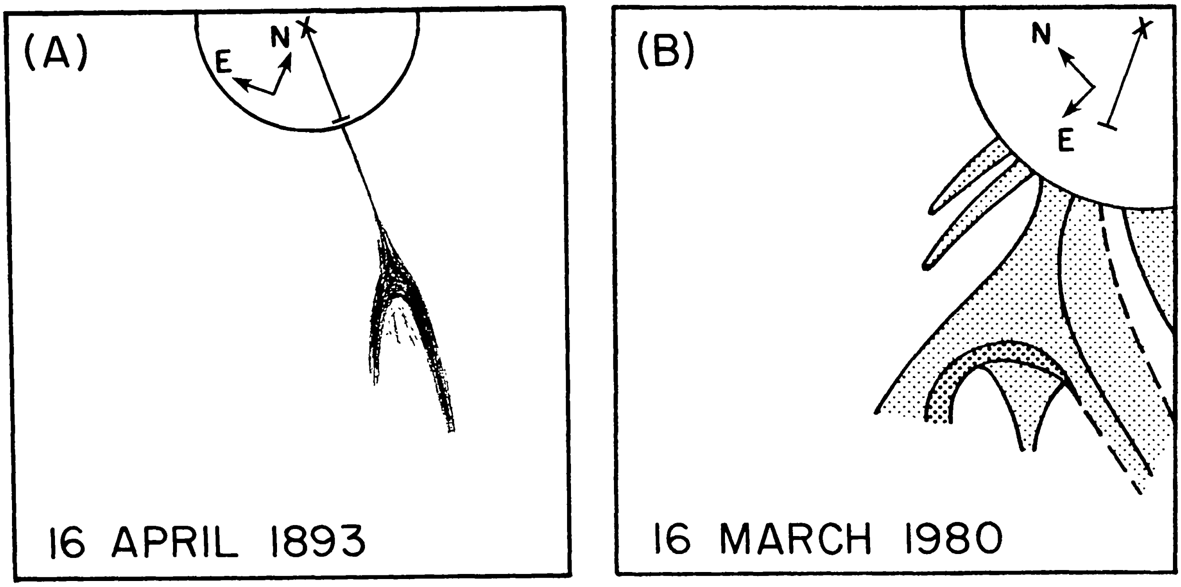

Fig. 1. (a) The eclipse comet of 1893 (Schaeberle, 1894a). The drawing was made by J. M. Schaeberle from the 32 s exposure plate made with the 40-ft focal length camera. Neighboring streamers are not shown. The tail of the comet can be traced on other negatives for more than 2° from the nucleus (Schaeberle, 1895). The narrow streamer drawn from the lunar disk to the nucleus is the comet's 'anti-tail'. Solar north and east are indicated and the center of the Sun is marked by a cross (×). The line drawn from Sun center has a length of 1 $R_\odot$. (b) A disconnected magnetic structure in a coronal transient (Illing and Hundhausen, 1983). The scale of the drawing is the same as in (a). The SMM coronagraph's occulting disk is drawn at 1.6 $R_\odot$.

2. The Eclipse Comet of 1893

2.1. SUMMARY OF OBSERVATIONS

The track of the 16 April, 1893 eclipse is shown in Figure 2. The site locations of the various eclipse expeditions sent out from Europe and North America are indicated on the map. Sky conditions varied from 'the highest class, ... absolutely free from clouds, smoke, or haze' at Mina Bronces in Chile, where totality lasted $2^{\mathrm{m}}\,53^{\mathrm{s}}$, to a slight haze at Fundium in Senegal, where totality was $4^{\mathrm{m}}\,11^{\mathrm{s}}$ in duration (Everett, 1893; Schaeberle, 1895; Lockyer, 1896; Todd, 1900).

In Chile, J. M. Schaeberle of the Lick Observatory used a 40-ft focal length eclipse camera with a five-inch objective lens (Eddy, 1971) to obtain seven large-scale (18 × 22 in) plates of the corona during totality with exposure times ranging from 0.25 to 32 s (Schaeberle, 1895). These large plates, on which the image of the moon was approximately 4.5 in diameter, were 'unequalled pictures of the corona with detail never before achieved' (Eddy, 1971; cf. Hale, 1896). A coronal feature observed on the 32 s exposure plate, and also on several smaller-scale Lick plates (Schaeberle, 1894c, 1895; Holden, 1894a), resembled a comet in some of its aspects (Schaeberle, 1894a) (Figure 1(a)). Plates obtained by the English expeditions to Brazil and Senegal established the (outward) motion (Figure 3) of the structure (Schaeberle, 1894b; Wesley, 1894). Since the comet was not observed outside of the eclipse, it was not possible to

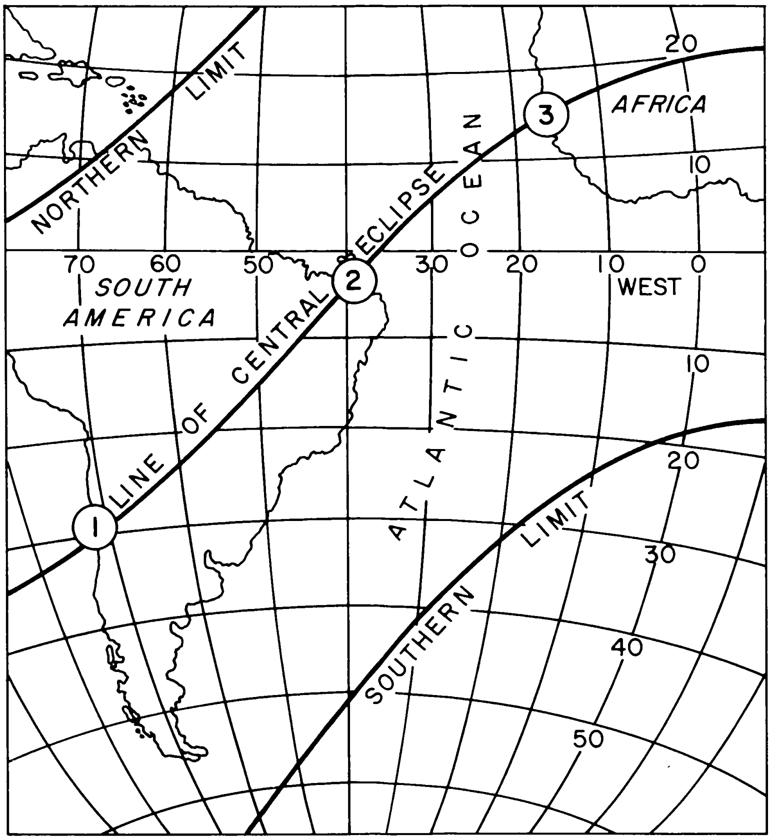

Fig. 2. The track of the 16 April, 1893 eclipse (Anonymous, 1892). The eclipse was observed from the following sites: (1) Chile – Mina Bronces (Lick Observatory) and Mina Aris (Harvard College Observatory); (2) Brazil – Para'-Curu (Royal Society of London); and (3) Senegal – Fundium (Royal Society of London, French Bureau of Longitudes) and Joal (French Bureau of Longitudes) (cf. Todd, 1900).

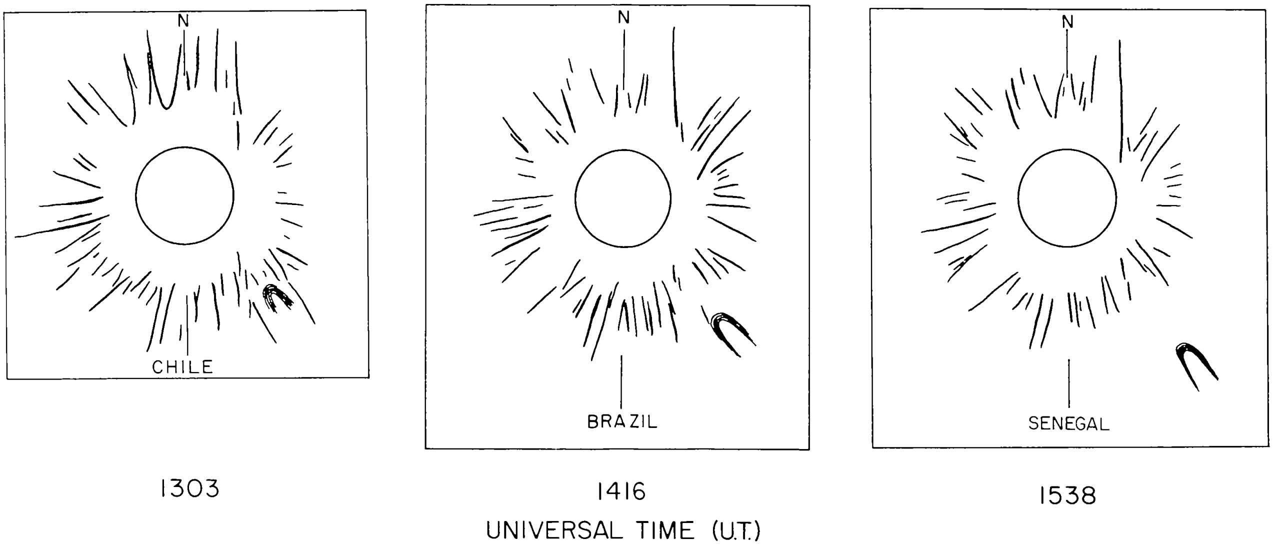

Fig. 3. Sketches of the eclipse photographs from Chile, Brazil, and Senegal which show the outward motion of the comet (from Wesley, 1894). Solar north is indicated. The ray connecting to the Sun is not drawn. Wesley comments that 'upon the English photographs (Brazil and Senegal) the denser portion of the comet is more or less lost in the coronal rays'.

calculate an orbit and determine the time of perihelion passage. Thus the comet is generally referred to as the eclipse comet of 1893 (Krueger, 1894; Holden, 1894b).

In the following sections we will continue, for convenience, to refer to the object observed in the corona during the 1893 eclipse as a comet, even while showing that it was, in all likelihood, a coronal mass ejection.

TABLE I

Characteristics of eclipse comets[a, b]

Date of discovery	Name of comet	Apparent mag. at discovery	Distance from Sun's center at discovery	Direction/ plane of sky speed (km s^{-1})	Sungrazer?	Ref.[c]
17 May, 1882	Eclipse comet of 1882; Tewfik	'striking object', 'observed by the naked eye'	$\sim 3\,R_\odot$	toward?/?	probable	1, 2, 3
1 Nov., 1948	Eclipse comet of 1948; 1948 XI	-3.0	$\sim 8\,R_\odot$	away/?	no	4, 5
30 Aug., 1979	Howard, Koomen, Michels; Solwind 1; 1979 XI	-3.5	$\sim 6\,R_\odot$	toward/284 ± 12	yes	6
26 Jan., 1981	Solwind 2; 1981 I	0.0	$\sim 8\,R_\odot$	toward/$\sim$250	yes	7
19 July, 1981	Solwind 3; 1981 XIII	-0.8 ($8\,R_\odot$)	$9.6\,R_\odot$	toward/$\sim$160	yes	5, 7
3 Nov., 1981	Solwind 4	~ 2	$\sim 8.5\,R_\odot$	toward/$\sim$160	yes	8, 9
24 Sept., 1983	Solwind 6	~ 0.5–0.0	$\sim 9\,R_\odot$	toward/$\sim$280	yes	8, 9
28 July, 1984	Solwind 5	~ 2.5	$\sim 6\,R_\odot$	toward/$\sim$220	yes	8, 9
16 Apr., 1893	Eclipse comet of 1893	-2.5 ± 1.5	$\sim 2.6\,R_\odot$	away/$\sim$90 ± 20	no	10

[a] Unconfirmed discoveries of comets or comet-like objects at eclipses have been reported by Dossin (1963) and Courten (1972). Todd (1900, p. 101) refers to two examples in antiquity of comets detected during eclipses. See Spratt (1988) for a separately compiled listing of eclipse comets.

[b] Between October 1987 and November 1988, seven more eclipse comets were discovered by the SMM coronagraph. Marsden (1988) reports that it is very probable that these seven comets, designated SMM 1–SMM 7, were sungrazers.

[c] References: (1) Lockyer, Tacchini, and Thollon (1882); (2) Abney and Schuster (1884); (3) Marsden (1967); (4) Anonymous (1948); (5) Kronk (1984); (6) Michels *et al.*, 1982; (7) Sheeley *et al.*, 1982; (8) M. Koomen, private communication, 1987; (9) Bortle, 1986; (10) this paper and references herein.

2.2. ARGUMENTS AGAINST THE COMET HYPOTHESIS

Table I contains a list of the nine 'eclipse comets', i.e., those comets discovered during natural or artificial solar eclipses, that were observed through mid-1987. As a group, the comets in Table I were bright objects in comparison with background stars near the Sun (although not necessarily in comparison with brighter coronal features). From a comparison of the images of the 1893 comet and Venus on an eclipse plate (HCO No. 454) taken by the Harvard College Observatory expedition to Chile, we estimate that the magnitude of this comet was -2.5 ± 1.5. The six Solwind comets, which had magnitudes ranging from -3.0 to $+2.5$, were found in unsubtracted coronagraph images; the eclipse comets of 1882 (magnitude unknown) and 1948 (-3.5) were both discovered by naked eye observation. The six Solwind comets have the appearance of relatively straight, thin streaks, while the tails of the 1882 and 1948 comets show curvature.

All eight of the comparison comets in Table I were distinctive objects, clearly separate and different from any coronal streamers. In contrast, the 1893 comet was not noticed visually by any of the observers along the eclipse path. Nor was it noted by any photographic observer other than Schaeberle. On the small-scale eclipse photographs taken in Chile such as the Dallmeyer print on the frontispiece of Schaeberle's (1895) report or on Harvard College Observatory (HCO) plate No. 454 that is reproduced as Figure 4(a), the comet appears to be an extension (slightly detached?) of the contour of the corona. It seems likely that the comet would not have been identified as an extra-coronal entity had Schaeberle not captured it on the longest-exposure (32 s) plate made with the 40-ft focal length camera. The drawing in Figure 1(a) was made mainly from this large-scale plate which is now missing from the Lick Observatory plate vault (G. Harlan, private communication, 1984).

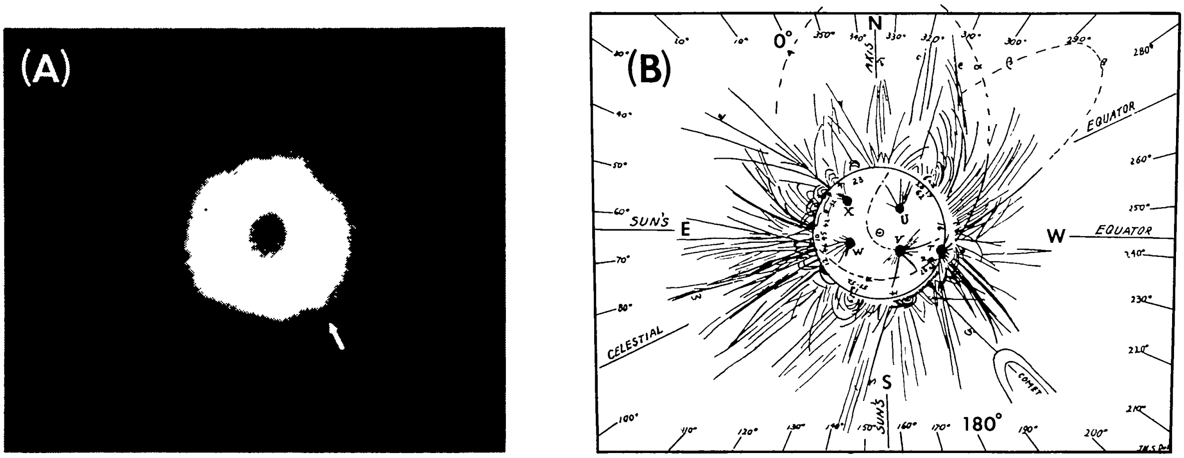

Fig. 4. (a) A photograph of the 16 April, 1893 corona taken by the Harvard College Observatory expedition to Chile (courtesy, Harvard College Observatory). The 'comet', indicated by the arrow, can be seen as an extension of the corona in the lower right-hand quadrant. The telescope appears to have been 'bumped' during the exposure. On the original plate (Harvard No. 454), the diameter of the moon is 3.5 mm. (b) Schaeberle's (1895) composite 'skeleton' drawing of the corona, with the same orientation as the photograph in (a).

Fortunately, Schaeberle sent a copy of this plate (a positive on glass at one-fifth scale) to the Royal Astronomical Society (RAS) (Wesley, 1894; Anonymous, 1893) where it was examined by the Society's secretary W. H. Wesley who compared it with smaller scale (image of the Moon ≤ 1.5 in diameter; Anonymous, 1894b) plates made by the English expeditions to Brazil and Senegal. Wesley was initially unable to identify the comet (Anonymous, 1894a) in the English plates. His comments (Wesley, 1894) are revealing:

> "I had previously examined the beautiful series of positives from the photographs taken by Professor Schaeberle in Chile, which had been sent to the R.A.S. from the Lick Observatory. In one of these (No. 6, 32 s exposure), taken with the photoheliograph, the object was quite distinct, and fairly resembled the sketch in *Astronomy and Astrophysics* (Figure 1(a)), though partly cut off by the edge of the plate, as mentioned by Professor Schaeberle. But none of the other positives from the Chile photographs, which were all taken with shorter exposures (with the 40-ft eclipse camera), showed any trace of the comet, and as it was so near the edge of the plate, which was not in that part free from photographic defects, I felt by no means certain of its reality.
>
> Upon receiving Professor Holden's (Director of Lick Observatory) letter I examined the original negatives of the British expeditions, both by myself and with others, but we entirely failed to identify the object shown on the single Chile photograph. Only in some of the Brazil negatives we noticed a forking of one of the coronal rays, but this did not seem sufficient to confirm Professor Schaeberle's discovery. It should be mentioned that, as the object on the Chile photograph was somewhat dense, I looked for a *dark patch* on the English negatives, and this may perhaps account for my failure to perceive it.
>
> ... Professor Holden kindly wrote to me again, enclosing a copy of one of the Chile negatives, and also one made from the positive of the Brazil photograph No. 3. Marks on the plates made the exact position of the object in question quite clear, and I had no difficulty in perceiving it upon both the plates ... It is evident that upon the English photographs the denser portion of the cometary object is more or less lost in the coronal rays, and I should rather have looked for the vacuity immediately outside this denser portion. This vacuity appears to be what I at first took for the space between the forks of a coronal ray. (Material in parentheses added to original text.)"

The glass positive that Wesley examined is extant and was kindly loaned to us by P. Hingley, Librarian of the RAS. An enhanced image from this plate is shown in Figure 5(b). The section of the glass plate containing the comet was digitized into a 512 × 512 array which was then 'cropped' to 304 × 375 and linearly expanded by a factor of three. A 32 color palate was used with 1 = black and 32 = white. The original brightness data values ranged from 100 to 4000. Values >600 were assigned the color white. Values in the range from 100–600 were linearly scaled from 1–256. Thus the 32 color table was 'wrapped around' eight times to increase the contrast of the faint coronal feature. This has the effect of making the edge of the corona appear dark in Figure 5(b). In Figure 5(a), we have traced the left edge of the coronal feature. Completing the sketch

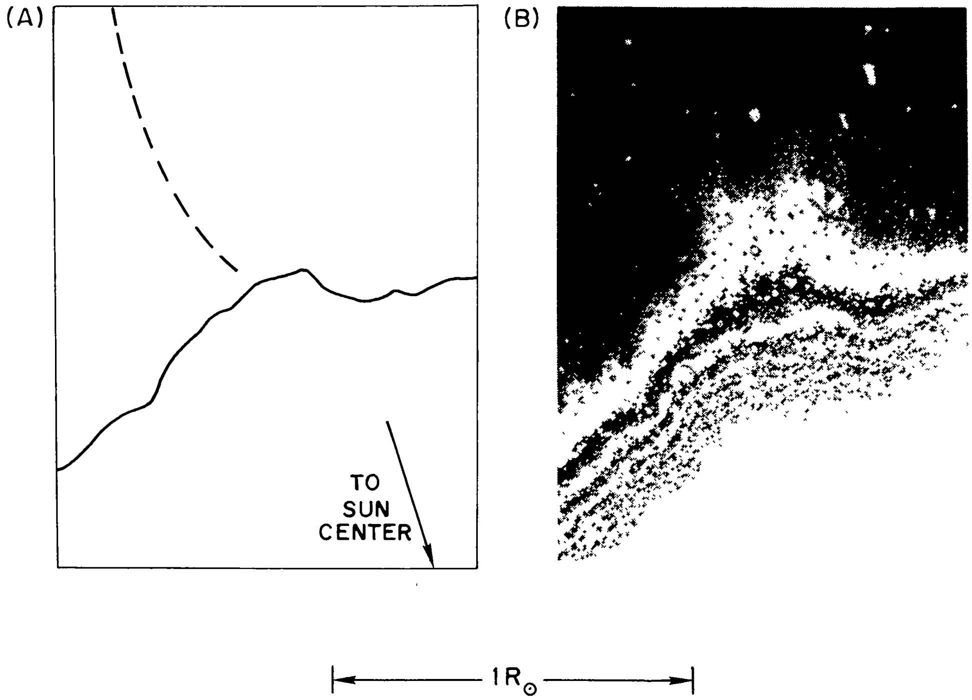

Fig. 5. (a) A sketch made from (b) a computer-enhanced image of the feature observed in the solar corona by J. M. Schaeberle during the 16 April 1893 solar eclipse. In (a) only the more clearly defined left edge of the feature depicted in Figure 1(a) has been drawn. The dark contours in (b) define the outer limit of the corona; they appear dark because of the image processing which is described in the text. The bright 'linear' feature to the left of the 'comet' appears to be an artifact since it is not visible in plates made with other telescopes in Chile.

to correspond to the drawing in Figure 1(a) is a subjective exercise best left to the reader.

The 1893 comet is atypical among the comets listed in Table I because it was not a member of the Kreutz family of sungrazers (Kreutz, 1888, 1891, 1901; Marsden, 1967). As indicated by its descriptive name, this well-known family of comets is distinguished by the small perihelion distances ($\lesssim 1$–$2\,R_\odot$) of its members. Comet Ikeya–Seki (1965 VIII) was a recent notable member of this group. All six of the comets discovered by the Solwind coronagraph on P78–1 were sungrazers (Michels *et al.*, 1982; Sheeley *et al.*, 1982; Bortle, 1986). (It is interesting to note that during the six years of Solwind observations no comets other than these six Kreutz members were detected within the coronagraph's field of view (N. Sheeley, private communication, 1987); however, prior to Solwind, non-sungrazing comet Kohoutek was observed in the field of view of Earth-orbiting coronagraphs (Anonymous, 1974).) The 1882 eclipse comet was probably also a member of this group (Marsden, 1967). The eclipse comets of 1948 and 1893 are the only events in Table I that were not sungrazers. The 1948 comet is the only listed event that was observed outside of eclipse, following discovery, and a definitive (non-sungrazing) orbit has been computed (cf. Marsden, 1982). Kreutz (1901) compared the measured positions of the 1893 comet with the orbits of sungrazing comets 1843 I (Great March Comet) and 1882 II (Great September Comet) and concluded that the 1893 comet was almost certainly not a sungrazer (cf. Marsden, 1967).

A consideration of the Sunward pointing tail or 'anti-tail' exhibited by the 1893 comet also raises arguments against the comet hypothesis. Schaeberle (1894a) describes the Sunward spike as a 'straight, slender, nearly radial streamer, ... conspicuously visible and distinctly isolated from the more inclined neighboring streamers not shown in the sketch' (Figure 1(a)). Such anomalous Sunward pointing tails (Sekanina, 1976; Pansecchi, Fulle, and Sedmak, 1987) result when dust spread out in the comet's plane of motion is viewed edge-on following perihelion passage. Z. Sekanina (private communication, 1987) points out that the narrow anti-tail observed in the 1893 event, which by itself would indicate that the Earth was in or very close to the comet's orbital plane (a rather extreme coincidence), is noticeably curved in Schaeberle's drawing and is aligned with one 'wing' of the ordinary tail, rather than bi-secting the angle between the two wings. This is contrary to both the observed and expected behavior of cometary dust ejecta. He also notes that anti-tails are displayed by dust-rich comets which scatter solar light and should, therefore, appear more prominent visually than on the blue sensitive plates which Schaeberle used (see Hale, 1896). Yet the comet was not observed visually at all.

The 1893 comet was undetectable (or at least unreported) by the observers in the northern hemisphere on nights prior to the eclipse and was not reported by anyone following the eclipse. During the eclipse, its magnitude changed from ≤ -1 during observations in Chile to a point where it was '*very faint*' (Schaeberle, 1895; italics in the original) or 'would have escaped observation altogether' (Wesley, 1894) on the plates taken from Senegal taken $2^{\mathrm{h}}35^{\mathrm{m}}$ later. The rapid decrease in brightness of the comet over this interval prompted Schaeberle (1895) to conclude that 'it (is) almost certain that the object was within the visible limits of the corona, and that ... perihelion passage occurred only a few hours (earlier)' (cf. Kreutz, 1901). In fact, a calculation of the distance of the comet from the Sun yields a separation of ~ 0.5 AU. This determination is based on the positions of the comet measured from plates taken in Chile and Senegal (Schaeberle, 1894; p. 106) by making use of the assumption, based on the apparent anti-tail, that the Earth was in the comet's orbital plane. In that case, the comet's motion would be entirely radial and any change in position angle would be due to the Earth's orbital motion. Since the position angle of the comet (measured eastward from the north ecliptic pole) changes from $221°16'$ to $214°59'$ (eastward motion) during the time of observations from Chile and Senegal, the comet must be located between the Sun and the Earth. To obtain the distance of the comet from the Sun, we determine the cometary motion in the ecliptic plane relative to the Sun, 5.5′ from Figure 6(a), and add it to the apparent motion of the Sun during $2^{\mathrm{h}}35^{\mathrm{m}}$,

$$(5.5' \times (1°/60')) + (2.58\ \mathrm{hr} \times (360°/(365.25\ \mathrm{day} \times (24\ \mathrm{hr}/1\ \mathrm{day})))) = 0.2°\,,$$

and then use the relationship (Figure 6(b))

$$\overline{CS} = d \times (0.2° \times (\pi/180°))\,,$$

where

$$\overline{CS} \simeq 2\pi \times 1\ \mathrm{AU} \times (2.58/24) \times (1/365.25)\,,$$

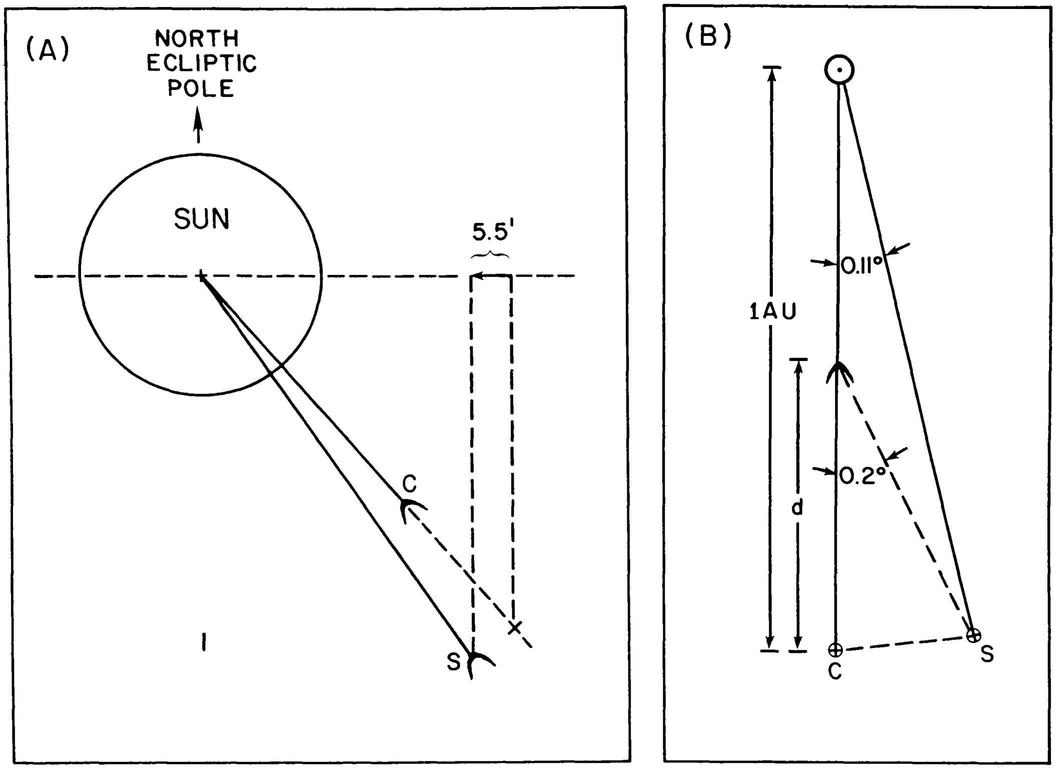

Fig. 6. (a) The positions of the comet in the plane of the sky as viewed from Chile (C; 13 : 03 UT) and Senegal (S; 15 : 38 UT). During this time the comet moves 5.5′ eastward relative to the Sun in the ecliptic plane. (b) A schematic view (not to scale) from the north ecliptic pole of the Sun–Earth-comet geometry at the time of observations from Chile (C) and Senegal (S) showing how the parameter *d*, the distance of the comet from the Earth, is determined.

to solve for *d*, the distance of the comet from the Earth,

$$d = 0.54\ \mathrm{AU}\,.$$

Thus the comet is apparently 0.46 AU from the Sun. At this relatively large inferred distance, any explanation for the pronounced brightness variations of the comet (which was most visible when it was seen in perspective closest to the coronal glare) in terms of a well-timed comet 'flaring' and subsequent rapid fading is suspect. It seems more likely that the object was not a comet located ~0.5 AU from the Sun but rather was a transient feature of the solar corona that had some non-radial motion (~30 km s^{-1} from Figure 6(a)).

2.3. THE CASE FOR A DISCONNECTED CORONAL TRANSIENT

The main argument that the feature observed in the corona of 1893 (Figure 1(a) and Figure 5(b)) was a disconnected coronal transient is its similarity to the disconnection event reported by Illing and Hundhausen (1983) (Figure 1(b)). The comet is a relatively subtle coronal feature that has an 'inverted arch' and pinches down into a narrow streamer. The tail of the comet is cut off in the sketch in Figure 1 but Schaeberle (1895; cf. Schaeberle, 1894a) notes that on the smaller-scale plates it is visible for ~10 $R_\odot$

beyond the nucleus. The radial speed of the convex (toward the Sun) surface, as determined from a time-height plot using the positions measured by Schaeberle (1894b, 1895) (angular distance in arc min from Sun center: Chile (40.0′ at 13 : 03 UT), Brazil (49.4′ at 14 : 16 UT), and Senegal (61.8′ at 15 : 38 UT)) and Wesley (1894) (Chile (45.5′), Brazil (52.5′), Senegal (~63.5′)), is ~90 ± 20 km s^{-1}. This outward speed is about half of the 175 km s^{-1} speed reported by Illing and Hundhausen for their 1980 event. The latitudinal extent of the 1893 comet was 12° vs ~40° for the 1980 disconnection event. An angular span of 12° is on the low side of, but within, the range of values of this parameter for the *leading* edges of coronal mass ejections observed by the Skylab (1973–1974) and SMM (1980, 1984–1986) coronagraphs (Hundhausen, 1987). Only about 5% of the transients observed by these two coronagraphs had angular spans $\leq 15°$. In contrast, Howard *et al.* (1985) report that ~25% of the mass ejections observed by Solwind (1979–1981) had spans in this range. The small angular width of the 1893 event and the presumed low speed of its leading edge (based on the relatively slow moving convex feature) agree best with the characteristics of the 'spike' structural class of mass ejections (avg. span = 15°; avg. speed = 297 km s^{-1}) described by Howard *et al.*

2.4. OBSERVATIONS OF SUNSPOTS AND PROMINENCES

If the eclipse comet of 1893 was, in fact, a coronal transient, then we might expect to find evidence for an associated flare, eruptive prominence, or post-flare loop system (cf. Kahler, 1977; Munro *et al.*, 1979; Webb and Hundhausen, 1987). While there are no reports of such phenomena, the available observations do suggest plausible origins for a coronal transient. Figures 7(a) and 7(b) show the state of the solar disk (Hale, 1893) and limb (Hale, 1896), respectively, during the time of the 16 April, 1893 eclipse. In each case the position and orientation of the slender ray connecting the comet to the Sun (see Figure 1(a)) is indicated by an arrow. An extrapolation of this ray toward disk center (Figure 7(a)) passes through an active region (Region 2928 in Greenwich photoheliographs). The Sun was near the maximum of cycle 13 in April, 1983 with a daily sunspot number (SSN) of 87 on the 16th (McKinnon, 1987). This SSN corresponds to an expected rate of ~ 0.5–1 transient per day (Howard *et al.*, 1986).

The elevated prominence to the right of the arrow in Figure 7(b) does not appear to change significantly (cf. Taylor, 1893) between the time of the observations in Chile (~ 13 : 00 UT) and Senegal (~ 15 : 40 UT), if one makes allowance for the different types of observations presented. Spectroscopic observations obtained by the English observers in Africa (Lockyer, 1896) also indicate that this prominence was not erupting (E. Tandberg-Hanssen, private communication, 1987). There is, however, evidence for evolution of this prominence prior to the eclipse since Hale (1893) notes that the two 'streamers', presumably the two line-like features near the arrow in Figure 7(a), were not present on 15 April. The great height of these 'streamers' on the 16th (~ 1.1×10^5 km; Hale, 1896) could not have resulted from solar rotation alone. Hale (1893) notes, with some ambiguity, that on the 17th 'this prominence (meaning either the "streamers" or the "long chain of prominences in the southwest") had greatly decreased in size'.

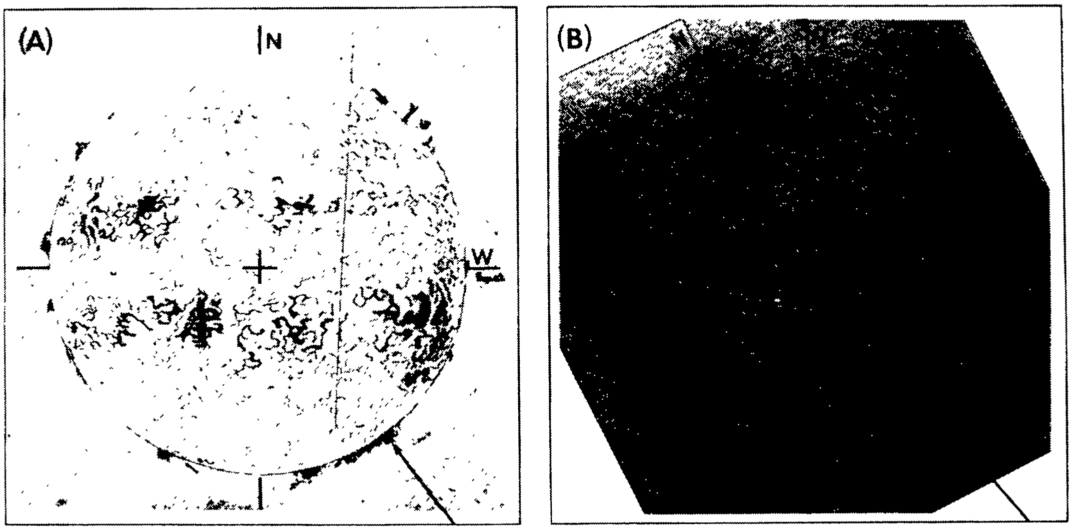

Fig. 7. (a) Drawing of prominences and faculae from observations made in the calcium II K-line by Hale (1893) in Chicago at ~ 15 : 00 UT on 16 April, 1893 during the time of the eclipse. Solar north is at the top of the figures. In both (a) and (b), the arrow indicates the position and orientation of the narrow ray that connects the comet to the Sun based on the diagram in Figure 4(b)). Schaeberle's (1895) written description of the prominences and streamers differs slightly and places this ray ~ 1.5° counterclockwise from the indicated position. (b) Prominences of 16 April, 1893 (Hale, 1896). (i) Outer circle: Photographed by J. M. Schaeberle with the 40-ft camera; plates most sensitive toward blue end of spectrum. (ii) Drawn by J. Fenyi from observations of the uneclipsed Sun in Hα at ~ 13 : 00 UT at Kalocsa, Hungary. (iii) Photographed by G. Hale in Ca II K-line at ~ 15 : 00 UT from Chicago. (iv) Inner circle: K-line images of prominences in the southwest quadrant of the Sun obtained by A. Fowler in Senegal at ~ 15 : 40 UT.

3. Possible Observations of Disconnected Mass Ejections during Other Solar Eclipses

Possible disconnection events have been observed during at least two other solar eclipses. An earlier (than the 1893 event) 'pre-discovery' observation of a coronal mass ejection has been reported by Eddy (1974) who noted evidence that the sunward side of the CME observed during the 18 July, 1860 eclipse 'pinched close' late in the event, resulting in an 'apparently detached structure'. Eddy estimated the speed of the leading edge to have been between 200–500 km s^{-1}. The suggestively named 'tennis racket' CME is a more recent example of a candidate disconnection event observed during a total solar eclipse. F. Diego's picture of the 16 February, 1980 eclipse (Anonymous, 1980) shows convex (toward the Sun) contours (see also Rust (1983) for C. Keller's eclipse photograph). Rusin and Rybansky (1983) calculate a leading edge speed of 610 ± 100 km s^{-1} for this CME.

4. Discussion

The eclipse comet of 1893 differed from the eight other eclipse comets in Table I in terms of its general appearance and orbit. The other comets discovered during natural or artificial solar eclipses were readily recognized as comets. The 1893 comet was a subtle coronal feature and its identification as a comet was initially controversial (Anonymous, 1894a; Schaeberle, 1894c; Holden, 1894a, b; Wesley, 1894). At least six, and probably seven, of the eight other eclipse comets were Kreutz sungrazers. The 1893 event almost certainly was not.

The observation of an anti-tail in the 1893 event and the rapid brightness variations it exhibited also raise arguments against the cometary hypothesis. The observation of a narrow cometary anti-tail requires that Earth be located in or very near the comet's orbital plane to provide the proper viewing perspective (Sekanina, 1974). Given this constraint, the inclination ($\sim 15°$) of the anti-tail in the 1893 comet to the axis of the main tail is paradoxical. In addition, the apparent bluish spectrum of this comet is unexpected in a (presumably) dust-rich comet with an anti-tail. The rapid brightness variations of the 1893 comet are best understood if the comet was very close to the Sun, near perihelion passage, but our calculations indicate that if this object was, in fact, a comet, then it was located at ~ 0.5 AU. The rapid fading of the feature from a magnitude ≤ -1 at the beginning of the eclipse to a point where it was barely visible 2.5 hr later constitutes unusual behavior for a comet but more understandable behavior for a coronal mass ejection.

On the longest exposure plate which Schaeberle obtained with the 40-ft focal length camera, the 'eclipse comet' resembles the disconnection event in 1980 reported by Illing and Hundhausen (1983). The 'comet' has a convex (toward the Sun) surface that pinches down into a narrow ray and propagates outward with a speed comparable to that of the 'inverted arch' observed in the 1980 event. Also, we note that both an active region and an apparently evolving prominence at the limb are located radially 'below' the comet.

Looking at Figure 4, one wonders how an object which blends rather smoothly into the background corona ever came to be identified as a comet. The 'comet', of course, was best seen on Schaeberle's original 32 s exposure plate from the 40-ft camera (Figure 1(a) and Figure 5(b)) and its distinctive appearance there was different from any conventional coronal form. Several factors probably contributed to the interpretation of this structure as a comet. First, a comet had been similarly discovered during an eclipse in 1882. Second, the original staff of the Lick Observatory was very familiar with comets and the interpretation of a diffuse moving feature as a comet would have quickly presented itself. Schaeberle had, previously to 1893, discovered two other comets by more conventional means (Marsden, 1982; Kronk, 1984) and E. E. Barnard, who verified the positions of the 1893 comet on the plates from the various expeditions (Schaeberle, 1894b, 1895), was a notable comet observer. Third, it was not known at the time if the corona could change over short time scales. In fact, that was one of the key questions to be answered by the widely separated English expeditions to Brazil and Senegal (Anonymous, 1894b). (The tentative conclusion by Wesley was that the corona did not change during the time of these observations (Todd, 1900).) Finally, it is probably worth noting that the eclipse comet was the one 'abnormal' feature that Schaeberle (1895) found in his large-scale plates that could not be explained by his 'mechanical theory of the corona' (Schaeberle, 1891) which ignored electrical and magnetic forces.

Other than adding a possible piece of evidence for the reconnection paradigm, to go with post flare loops (Bruzek, 1964; Kahler, 1977), moving type IV radio burst plasmoids (e.g., Wild, 1970), magnetic clouds (Klein and Burlaga, 1982; Burlaga and Behannon, 1982), and the disconnection event reported by Illing and Hundhausen (1983), what can we learn from candidate disconnection events observed during natural solar eclipses? There are two points which prompt speculation, one involving the speeds of disconnected CMEs and the other their time of occurrence in the solar cycle. We will discuss each of these points in turn.

The speeds of the outward propagating convex surfaces in the 1893 (~ 90 km s^{-1}) and 1980 (175 km s^{-1}) disconnection events were relatively low. Moreover, the speed of the concave (toward the Sun) surface(s) observed earlier in the 1980 event was only 40–50 km s^{-1}. These low speeds suggest that, for some reason, manifestations of magnetic disconnection ('inverted arches' and 'necking down') may be easier to observe in less energetic events. There is some evidence for this in the eight candidate disconnection events observed in 1980 by SMM. The median speed of the (concave) leading edge in these events was 158 km s^{-1} (range from 35 to >490 km s^{-1}) (D. Webb, private communication, 1987), compared to 290 km s^{-1} for the total sample of 79 mass ejections observed by the SMM coronagraph in 1980 (63 with measured plane of sky speeds) (Webb, 1987; Hundhausen, 1987). One of the two CMEs with disconnection characteristics pointed out by Anzer and Pneuman (1982) from the Skylab data set was also a slow event; Hildner *et al.* (1975a) obtained a leading edge speed of 175 km s^{-1} for the 26–27 August, 1973 CME. The other possible disconnection event noted by Anzer and Pneuman, on 10 June, 1973, had a leading edge speed of ~ 500 km s^{-1} (Hildner *et al.*, 1975b). The two other candidate disconnection events observed during natural solar eclipses had speeds of 200–500 km s^{-1} (18 July, 1860) and 610 ± 100 km s^{-1} (16 February, 1980).

It is interesting to note that all three of the candidate disconnected mass ejections observed at the time of total eclipses occurred during years of maximum sunspot number. (The average yearly sunspot numbers for 1860, 1893, and 1980, were 95.8, 85.1, and 154.6, respectively (McKinnon, 1987).) One obvious reason for this result is that the CME occurrence rate may vary directly with sunspot number (Howard *et al.*, 1986, but see Hundhausen, 1987). A possible contributing factor may be that the streamer belt, from which CMEs appear to originate during solar minimum (Hundhausen, 1987), is dispersed at solar maximum and background streamers, against which subtle disconnection features must be detected, are less of a hindrance at this time.

Given the paucity of reported cases of disconnected CMEs in the extensive data bases acquired by Skylab, SMM, and Solwind, it is surprising that three candidate disconnection events have been observed during naturally occurring solar eclipses. The only apparent advantage of natural eclipse observations over spaceborne coronagraph observations is the smaller size of the occulting (lunar) disk (Eddy, 1974) and this alone seems unlikely to account for the 'ease of discovery' of disconnection events at totality. Systematic searches of the various satellite coronagraph data sets for evidence of magnetic disconnection are necessary to establish or disprove the existence of disconnection events. Comprehensive studies on this point are warranted given the prominent role played by reconnection in current theories of flares and ejecta but, to date, none have appeared in the literature.

Acknowledgements

I thank B. Jackson, S. Kahler, M. Koomen, and D. Webb for helpful discussions and critical readings of this manuscript. I am grateful to B. Marsden and Z. Sekanina for kindly sharing their knowledge of comets. Special thanks go to P. Hingley for loaning the copy of Schaeberle's plate No. 6 from the RAS archives, K. Janes for digitizing the plate, M. Herant for producing the computer-enhanced image shown in Figure 5, and J. Browne for the photographic work. I am indebted to M. Hazen for the loan of the HCO eclipse plate, to M. Kurtz for photometry of the HCO plate, to G. Green for a translation of the Kreutz (1901) paper, and to M. Koomen and N. Sheeley, Jr., for providing unpublished data for the three most recent Solwind sungrazers. I also wish to thank R. Black, M. Chibnall, K. Cudworth, R. Dreiser, J. Eddy, D. Hardy, G. Harlan, F. Miller, D. Osterbrock, and E. Watson-Jones for their help with the search for data for the 1893 event.

References

Abney, W. de W., and Schuster, A.: 1884, *Phil. Trans.* **175**, 253.
Anonymous: 1892, *Nature* **46**, 201.
Anonymous: 1893, *J. Brit. Astron. Assoc.* **4**, 98.
Anonymous: 1894a, *Observatory* **17**, 253.
Anonymous: 1894b, *Astron. Astrophys.* **13**, 82.
Anonymous: 1948, *The Illustrated London News* **123**, 629.
Anonymous: 1974, *Sky Telesc.* **47**, 91.
Anonymous: 1980, *Sky. Telesc.* **59**, 383.
Anzer, U. and Pneuman, G. W.: 1982, *Solar Phys.* **79**, 129.
Bortle, J. E.: 1986, *Sky Telesc.* **72**, 547.
Bruzek, A.: 1964, *Astrophys. J.* **140**, 746.
Burlaga, L. F. and Behannon, K. W.: 1982, *Solar Phys.* **81**, 181.
Courten, H. C.: 1972, *Umschau Wiss. Tech.* **72**, 562.
Dossin, F.: 1963, *Compt. Rend. Acad. Sci. Paris* **257**, 2246.
Eddy, J. A.: 1971, *J. Hist. Astron.* **2**, 1.
Eddy, J. A.: 1974, *Astron. Astrophys.* **34**, 235.
Everett, A.: 1893, *Observatory* **16**, 200.
Hale, G. E.: 1893, *Astron. Astrophys.* **12**, 450.
Hale, G. E.: 1896, *Astrophys. J.* **3**, 374.
Hildner, E., Gosling, J. T., Hansen, R. T., and Bohlin, J. D.: 1975a, *Solar Phys.* **45**, 363.
Hildner, E., Gosling, J. T., MacQueen, R. M., Munro, R. H., Poland, A. I., and Ross, C. L.: 1975b, *Solar Phys.* **42**, 163.
Holden, E. S.: 1894a, *Astron. Nach.* **136**, No. 3253, 203.
Holden, E. S.: 1894b, *Publ. Astron. Soc. Pacific* **6**, 295.
Howard, R. A., Sheeley, Jr., N. R., Koomen, M. J., and Michels, D. J.: 1985, *J. Geophys. Res.* **90**, 8173.
Howard, R. A., Sheeley, Jr., N. R., Michels, D. J., and Koomen, M. J.: 1986, in R. G. Marsden (ed.), *The Sun and the Heliosphere in Three Dimensions*, XIX ESLAB Symposium, D. Reidel Publ. Co., Dordrecht, Dordrecht, p. 107.

Illing, R. M. E. and Hundhausen, A. J.: 1983, *J. Geophys. Res.* **88**, 10210.

Kahler, S.: 1977, *Astrophys. J.* **214**, 891.

Klein, L. W. and Burlaga, L. F.: 1982, *J. Geophys. Res.* **87**, 613.

Kopp, R. A. and Pneuman, G. W.: 1976, *Solar Phys.* **50**, 85.

Kreutz, H.: 1888, *Publ. Sternw. Kiel*, No. 3.

Kreutz, H.: 1891, *Publ. Sternw. Kiel*, No. 6.

Kreutz, H.: 1901, *Astron. Abhandl. 1*, No. 1, 60.

Kronk, G. W.: 1984, *Comets, a Descriptive Catalog*, Enslow Publ. Inc., Hillside, NJ.

Krueger, A.: 1894, *Astron. Nach.* **136**, No. 3253, 203.

Lockyer, J. N.: 1896, *Phil. Trans.* **187**, 551.

Lockyer, J. N., Tacchini, P., and Thollon, L.: 1882, *Observatory* **5**, 180.

Marsden, B. G.: 1967, *Astron. J.* **72**, 1170.

Marsden, B. G.: 1982, *Catalogue of Cometary Orbits*, 4th ed., Central Institute for Astronomical Telegrams, Cambridge, MA.

Marsden, B. G.: 1988, *IAU Central Bureau for Astronomical Telegrams*, Circular Nos. 4621, 4648, 4660, 4668, 4684, and 4692.

McKinnon, J. A.: 1987, *Sunspot Numbers: 1610–1985*, Report UAG-95, WDC-A, Boulder, CO.

Michels, D. J., Sheeley, N. R., Jr., Howard, R. A., and Koomen, M. J.: 1982, *Science* **215**, 1097.

Munro, R. H., Gosling, J. T., Hildner, E., MacQueen, R. M., Poland, A. E., and Ross, C. L.: 1979, *Solar Phys.* **61**, 201.

Pansecchi, L., Fulle, M., and Sedmak, G.: 1987, *Astron. Astrophys.* **176**, 358.

Pneuman, G. W.: 1980, in M. Dryer and E. Tandberg-Hanssen (eds.), 'Solar and Interplanetary Dynamics', *IAU Symp.* **91**, 317.

Rusin, V. and Rybansky, M.: 1983, *Bull. Astron. Inst. Czech.* **34**, 257.

Rust, D. M.: 1983, *Rev. Geophys. Space Phys.* **21**, No. 2, 349.

Schaeberle, J. M.: 1891, in *Contr. Lick Obs.* No. 2, p. 47.

Schaeberle, J. M.: 1894a, *Astron. Astrophys.* **13**, 307.

Schaeberle, J. M.: 1894b, *Astron. J.* **14**, 46.

Schaeberle, J. M.: 1894c, *Publ. Astron. Soc. Pacific* **6**, 237.

Schaeberle, J. M.: 1895, *Contr. Lick Obs.*, No. 4.

Sekanina, Z.: 1974, *Sky Telesc.* **47**, 374.

Sekanina, Z.: 1976, in B. Donn, M. Mumma, W. Jackson, M. A'Hearn, and R. Harrington (eds.), *The Study of Comets*, NASA SP-393, GPO, Washington DC, p. 893.

Sheeley, N. R., Jr., Howard, R. A., Koomen, M. J., and Michels, D. J.: 1982, *Nature* **300**, 239.

Spratt, C. E.: 1988, *Roy. Astron. Soc. Can. (National Newsletter)* **82**, No. 2, 19.

Taylor, A.: 1893, *J. Brit. Astron. Assoc.* **3**, 420.

Todd, M. L.: 1900, *Total Eclipses of the Sun*, Little, Brown, and Co., Boston, MA, p. 157ff.

Webb, D. F.: 1987, NCAR Technical Note. 297 + STR.

Webb, D. F. and Hundhausen, A. J.: 1987, *Solar Phys.* **108**, 383.

Wesley, W. H.: 1894, *Observatory* **17**, 349.

Wild, J. P.: 1970, *Proc. Astron. Soc. Australia* **1**, 365.