ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES
Astron. Astrophys. Suppl. Ser. **146**, 1–5 (2000)

The onsets of disconnection events of comet P/Halley on 1985 December 13-14 and 1986 February 22

M.R. Voelzke[1] **and O.T. Matsuura**[2]

[1] Institut für Astrophysik und Extraterrestrische Forschung, Universität Bonn, Auf dem Hügel 71, D-53121 Bonn, Germany
[2] Instituto Astronômico e Geofísico da Universidade de São Paulo, Avenida Miguel Stéfano, 4200, 01060-970 São Paulo, Brazil

Received August 31, 1999; accepted May 19, 2000

Abstract. This work compares cometary and solar wind data with the purpose of determining the solar wind conditions associated with comet plasma tail disconnection events (DEs). The cometary data are from *The International Halley Watch Atlas of Large-Scale Phenomena* (Brandt et al. 1992a). A systematic visual analysis of the atlas images (Voelzke & Matsuura 1998) revealed, among other morphological structures, 47 DEs. The solar wind data are in situ measurements from IMP-8, ICE and PVO, which are used to construct the variation of solar wind speed, density and dynamic pressure during the analysed interval. Data from these same spacecraft plus Vega 1 were used to determine the times of current sheet crossings. These data were fitted to heliospheric current sheet curves (Hoeksema 1989) extrapolated from the corona into the heliosphere in order to determine the best-fit coronal source-surface radius for each Carrington rotation. This work presents the kinematic analysis for two onsets of DEs (1985 December 13.5 and 1986 February 22.2). The DE onset time, when the comet supposedly crossed a magnetic sector boundary, is determined assuming that the disconnected plasma moves away from the nucleus at constant velocity (Voelzke & Matsuura 1998). This is compared with the analysis of (Yi et al. 1994b) which determined the time of disconnection assuming constantly accelerated linear motion. The velocity varies broadly from one DE to another. In this paper, we report the results of an analysis of four DEs observed from 13 through 14 December 1985 and on 22 February 1986. From a kinematic analysis of the wide-field photographic images we calculated the disconnection time of the 1985 December 13-14 DEs to be December 13.5 and of the 1986 February 22 to be February 22.2, which are in good agreement with Yi et al. (1994b). The solar wind conditions around comet P/Halley, inferred by corotation of IMP-8 data to the comet, were such that comet P/Halley had just crossed the interplanetary magnetic field (IMF) sector boundary; the solar wind density was, respectively, 15 cm^{-3} and 7 cm^{-3}; the solar wind speed was, respectively, 370 km s^{-1} and 500 km s^{-1}. We conclude that our results corroborate the idea that DEs are associated with sector boundary crossings and that the magnetic reconnection plays an important role in the formation of DEs and can be considered as the triggering mechanism (Niedner & Brandt 1978; Brandt et al. 1999).

Key words: comets — comet P/Halley plasma dynamics — disconnection events

1. Introduction

This work is based on a systematic analysis of images of comet P/Halley collected during its last apparition as part of the International Halley Watch program by the Large Scale Phenomena Network of observatories. A subset of images (531 out of 1439) from *The International Halley Watch Atlas of Large-Scale Phenomena* (Brandt et al. 1992a), covering the period from 1985 September 17 to 1986 July 06, were selected on the basis of their many conspicuous morphological structures along the cometary tail. They were visually and systematically analysed for the purpose of identification and classification (Voelzke & Matsuura 1998).

Occasionally, the entire or partial plasma tail separates from the comet and drifts away (antisunward), followed by renewal of the plasma tail. The cyclic nature of this phenomenon, called a disconnection event (DE), was noted long ago (Barnard 1899, 1920). Disconnection events (Niedner & Brandt 1979; Jockers 1985; Celnik et al. 1988; Delva et al. 1991; Brandt et al. 1992b; Voelzke & Matsuura 1998) are common. They occur over wide ranges in heliocentric distance, heliospheric latitude, and phases

Send offprint requests to: M.R. Voelzke,
e-mail: mvoelzke@astro.uni-bonn.de

of the solar cycle. Although the mechanism remained unresolved, the solar wind was suspected to play a major role in the phenomena of comet plasma tail DEs. Many ideas were suggested to explain the cyclic phenomena of DEs (Brandt 1990). The current competitive theories to explain the onset of DEs can be grouped into three classes based on the triggering mechanisms: (a) Ion production effects (Wurm & Mammano 1972), (b) Pressure effects (Ip & Mendis 1978; Ip 1980; Jockers 1985; Wegmann 1995; Wegmann 1998), and (c) Magnetic reconnection (Niedner & Brandt 1978; Russell et al. 1986; Brandt et al. 1992c; Yi et al. 1996; Yi et al. 1998; Brandt et al. 1999). In this work the comet P/Halley DEs are interpreted in terms of the location of the magnetic sector boundaries derived from solar magnetic field data on the "source-surface" (Hoeksema et al. 1983) and the expansion of the solar wind.

2. Data

A disconnection event was found in 47 out of the selected 531 images from *The International Halley Watch Atlas of Large-Scale Phenomena* (Brandt et al. 1992a), covering the period from 1985 November 13 to 1986 April 15. They were visually and systematically analysed to derive their onset times (Table 1), i.e., the time when the comet supposedly crossed a magnetic sector boundary in the solar wind.

The 47 DEs documented in these 47 different images allowed the derivation of the 19 DE onsets. The list of them and references to analyses and discussions are given in Table 1.

Table 1. Onset time of 19 DEs

DE number	Onset time (UT)	Possibly related reports
1	1985 Nov. 12.76	
2	1985 Dec. 05.61	
3	1985 Dec. 13.54	Niedner (1986); Yi et al. (1994b)
4	1985 Dec. 14.16	
5	1986 Jan. 01.90	
6	1986 Jan. 07.52	
7	1986 Jan. 09.63	Niedner (1986); Tomita et al. (1987); Niedner et al. (1991)
8	1986 Jan. 10.16	Niedner (1986); Tomita et al. (1987); Niedner et al. (1991)
9	1986 Jan. 10.76	
10	1986 Feb. 22.17	Niedner (1986); Yi et al. (1994b)
11	1986 Mar. 08.90	Niedner (1986); Wu & Qiu (1987); Niedner & Schwingenschuh (1987)
12	1986 Mar. 14.05	
13	1986 Mar. 15.87	Feldman et al. (1986); Celnik et al. (1988); Yi et al. (1994a)
14	1986 Mar. 20.01	
15	1986 Apr. 03.38	
16	1986 Apr. 06.45	Niedner (1986); Celnik et al. (1988)
17	1986 Apr. 07.70	
18	1986 Apr. 11.75	
19	1986 Apr. 15.34	

3. Image analysis

3.1. Disconnection events

The corrected cometocentric velocity of a given DE was calculated using pairs of frames. Assuming a constant velocity (Voelzke & Matsuura 1998), the onset time of the event could then be extrapolated for 19 individual DEs. This time is supposedly related, with a certain delay, to the time when the comet crossed the boundary between interplanetary magnetic sectors of the solar wind. Magnetohydrodynamic simulations (Yi et al. 1996) of a comet crossing the heliospheric current sheet have confirmed the frontside magnetic reconnection between the reversed interplanetary magnetic fields (Niedner & Brandt 1978), and were able to reproduce the typical morphological evolution of a DE. They also strongly support the association of comet P/Halley DEs with the heliospheric current sheet crossings (Yi et al. 1994b; Yi et al. 1996). A correction for the velocity arises from projection effects in the plane of the sky. It was applied for the apparent distances according to the equations of Yeomans (1981). Before the perihelion passage, nine onsets of DEs were discovered at heliocentric distances R ranging from 1.75 to 0.86 AU. The average value of the corrected cometocentric velocity was $V_{\rm c} = (260 \pm 87)$ km s^{-1}, with $V_{\rm c}$ ranging from 62 to 842 km s^{-1}. After perihelion, ten onsets of DEs were discovered with R ranging from 0.66 to 1.41 AU. The average value of $V_{\rm c}$ was (130 ± 38) km s^{-1}, ranging from 33 to 407 km s^{-1}. All numerical values determined in this work are expressed within their estimated accuracies. Values depending on distances determined in the cometocentric frame of reference contain larger uncertainties because of ambiguities in positioning the cometary nucleus. Table 1 presents the onset times for 19 DEs. Reports by other authors on a DE occurring within ± 0.5 day were considered possibly related and are also cited in Table 1.

The two onsets of DEs discussed in this work (1985 December 13.5 and 1986 February 22.2) are cases that illustrate a good correlation with a solar wind feature such as the sector boundary.

Solar wind conditions were inferred from the corotated spacecraft plasma and magnetic field measurements for each event and the relationship between these DE onsets and the heliospheric current sheet (the sector boundary)

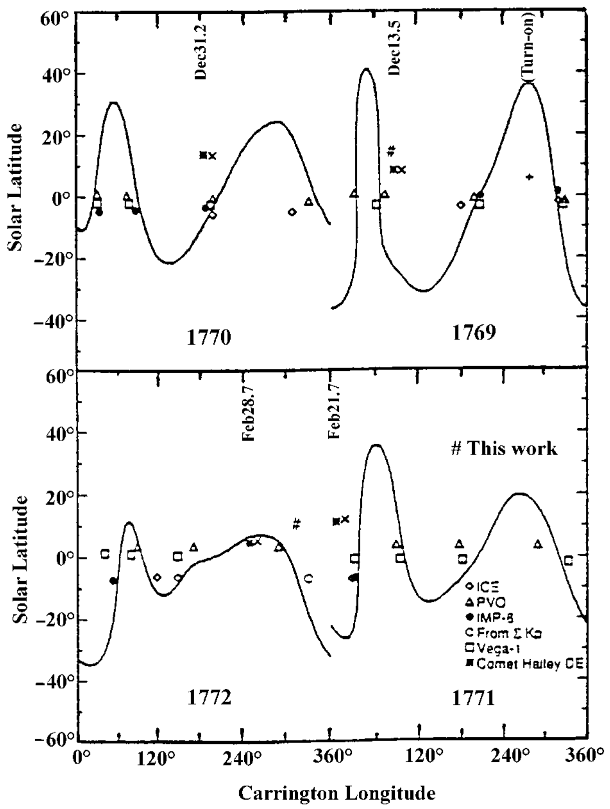

Fig. 1. Carrington-Niedner Diagram. The solid line is the heliospheric current sheet location as determined by Yi et al. (1994b). The sector boundary crossings as determined by spacecraft (ICE, PVO, IMP-8 and Vega-1) are marked as shown in the legend. One sector boundary crossing estimated from the geomagnetic index, ΣK_{p}, is also marked. The onsets of DEs determined in this work (1985 December 13.5: upper panel and 1986 February 22.2: lower panel) are marked with (#) while the onsets calculated by Yi et al. (1994b) are marked with asterisks (*). The $\times$ shows a one day shift corresponding to a one day delay between the sector boundary encounter and the DE for the sunward reconnection model. The + marks the turn-on of plasma activity. The point representing the onset of 1985 December 13.5 (determined in this work) is slightly displaced from the onset determined by Yi et al. (1994b) in order to avoid crowding, since they are at the same time and position. The onset of 1986 February 22.2 has a small offset in relation to the one of 1986 February 21.7 determined by Yi et al. (1994b). The coronal source surface 2.0 solar radii is used for Carrington rotation 1769, and the coronal source surface 2.5 solar radii is used for Carrington rotations 1770-1772

is presented in Fig. 1. This method is fully described by Yi et al. (1993).

3.2. Analysis of individual onsets of DEs

For the purpose of determining the solar wind conditions associated with cometary plasma tail DEs, we have investigated the association of the DEs of 1985 December 13-14 and 1986 February 22 with the heliospheric current sheet, high-speed streams, solar wind density, and dynamic pressure changes.

The two onsets of DEs (1985 December 13.5 and 1986 February 22.2) are determined by assuming that in a given DE the disconnected plasma moves away from the nucleus at constant velocity (Voelzke & Matsuura 1998). The onset of 1985 December 13.5 was determined through systematic visual analysis of three images: LSPN 3839 (13.78403 UT), LSPN 216 (14.06944 UT) and LSPN 217 (14.08819 UT). The last two images were also considered by Yi et al. 1994b in their analysis but not the first one. The corrected cometocentric velocity V_{c} calculated from these three images is 62 km s^{-1}. At that time, the solar wind speed was 370 km s^{-1} and the solar wind density was 15 cm^{-3} (Yi et al. 1994b). In our work we considered that the other images analysed by Yi et al. (1994b), when they calculated the disconnection time of the onset from December 13.5, do not depict a DE but only show a solitary wave (soliton) and a wavy structure in the case of image LSPN 219 (14.12986 UT). While the wavy structures denote undulations or a train of waves, the solitons refer to formations usually called kinks (Tomita et al. 1987). In our analysis we considered that images AON-850472 (14.81000 UT) and LSPN 3843 (14.91285 UT) depicted a DE, but with a different disconnection time, i.e., with onset on 1985 December 14.16 UT. The spacecraft sector boundary crossings (Vega-1 on December 24.0 and PVO on December 29.0), the heliospheric current sheet extrapolated from the corona, and the DE onset locations of comet P/Halley are all plotted in Fig. 1 (upper panel).

The onset of 1986 February 22.2 was determined through the systematic visual analysis of one image, namely LSPN 2376 (22.77933 UT). This image is also considered by Yi et al. (1994b) in their analysis. The corrected cometocentric velocity used in this image is $V_{\mathrm{c}} = 100$ km s^{-1}. At that time, the solar wind velocity was 500 km s^{-1} and the solar wind density was 7 cm^{-3} (Yi et al. 1994b). In our work we considered that the other image analysed by Yi et al. (1994b) for calculation a DE onset of February 21.7, does not depict a DE but only shows a wavy structure (image LSPN 1781: 22.12569 UT). To determine the onset of the DE in image LSPN 2376 we used the same value of the cometocentric velocity determined through systematic visual analysis of the images LSPN 2382 (09.77716 UT), LSPN 1384 (10.43958 UT) and LSPN 2383 (10.73808 UT). These images depicted a DE with the disconnection time on 1986 March 08.90 UT, in our analysis the nearest to the onset of 1986 February 22.2. Of course, using this velocity contributes to a larger uncertainty in the determination of the onset of the DE in image LSPN 2376. Unfortunately, this assumption was our only means for determining the disconnection time from only one image. We considered that the images LSPN 1357 (02.00000 UT), LSPN 1354 (02.47847), LSPN 1356 (02.49010) and LSPN 1358 (02.50148), used by Yi et al. (1994b) to determine the onset of 1986 February 28.7, did not show a DE, but only wavy structures and solitons. The sector boundary crossings by spacecraft (IMP-8 on February 11.0, ICE on February 13.0 and Vega-1 on February 16.0), the spacecraft measurements and the comet P/Halley DE locations are plotted in Fig. 1 (lower panel).

Wegman (1995) showed that a strong interplanetary shock, whose Mach number in the frame of the ambient solar wind is larger than two, can make a density hump in the plasma tail and concluded that about 25% of all tail disconnections must be caused by interplanetary schocks.

The solar wind dynamic pressure does not vary strongly because the solar wind density for the DEs analysed here increases when the solar wind velocity decreases and vice versa. Hence these DEs were found to be uncorrelated with high-speed streams and high-density regions.

Yi et al. (1993) considered the possible association of changes in the Alfvén Mach number with DEs and concluded that such an association was unlikely. The coronal mass ejection data in *Solar Geophysical Data* (Wagner 1984) are also not supportive of a correlation between the interplanetary shocks and DEs (Yi et al. 1994a; Brandt et al. 1999).

In order to minimize the impact of uncertainties in any single event, Brandt et al. (1999) analysed the comet P/Halley DEs as a group for correlation with solar wind features. Their results confirm that the DEs are associated with crossings of the heliospheric current sheet.

The onsets of DEs calculated in this work, an independent analysis of the observational data, are in good agreement with Brandt et al. (1999).

3.3. Carrington-Niedner diagram

The relationship between DEs and the solar wind conditions can be displayed in one coordinate system referenced to a standard heliospheric distance, such as the system of Carrington longitude on the coronal source surface (Yi et al. 1994b). This is performed by corotating comet P/Halley DE locations, solar wind observations and the heliospheric sector boundaries onto the Carrington longitude at the coronal source surface. One Carrington rotation is defined as the mean synodic rotation period of sunspots and is equal to 27.2753 days. These rotation intervals have been numbered consecutively from the first Carrington rotation beginning on 9 November 1853. At the commencement of a new rotation the center of the solar disc is defined to have a Carrington longitude $\phi = 0°$. Carrington longitude is measured in a system rotating with the sun (Stix 1989).

If the solar wind speed and the sidereal spiral pattern speed ($14.4°$ day^{-1}) remain constant, then the solar wind source in the corona ejects material into an archimedian spiral pattern. We follow the same procedure of Yi et al. (1994b) and trace (corotate) the solar wind features at the spacecraft (IMP-8, PVO, ICE or Vega-1) to the footprints of the archimedian spiral on the coronal source surface. The same approach applies to the location of the heliospheric neutral current sheet, calculated from a potential field-source model of the coronal magnetic field based on photospheric magnetic field observations (Hoeksema 1984; Hoeksema 1989). At the source surface, all magnetic field lines are assumed to be frozen in the plasma and are carried radially outward into the heliosphere by the solar wind. The neutral line on the coronal source surface thus maps radially outward to form the heliospheric current sheet. This interplanetary magnetic field (IMF) structure, heliospheric current sheet, when projected to 1.0 AU, is in reasonable agreement with the observations (Hoeksema 1989). The neutral line calculations are available for different source surfaces.

We used the Carrington-Niedner diagram illustrated by Fig. 5 in Yi et al. (1994b) to show our calculated onsets (Fig. 1) and to compare with the onsets calculated by these authors, who assumed a constantly accelerated linear motion to determine the time of the disconnections. The coronal source surface at 2.5 solar radii fits the spacecraft data best for Carrington rotations 1770 through 1772, while the coronal source surface at 2.0 solar radii produces the lowest root mean square (rms) value for Carrington rotation 1769 (Yi et al. 1994b).

The positions of our calculated onsets (1985 December 13.5 and 1986 February 22.2) are in a good agreement with the onsets calculated by Yi et al. (1994b) (1985 December 13.5 and 1986 February 21.7) although the kinematic analyses are different (Fig. 1). In both cases the DE locations have good correspondence with the sector boundary crossings. This corroborates the hypothesis that the onsets of DEs occur because the magnetic reconnection effect acts as triggering mechanism.

4. Discussion and conclusions

The distribution of DEs in time and heliocentric distances shows a bimodal character, possibly related to the spatial distribution of the magnetic sector boundaries in the interplanetary medium (Voelzke & Matsuura 1998). This result corroborates the idea that DEs are associated with sector boundary crossings and that such an association is an essential element in the morphological development of DEs in plasma tails (Niedner & Brandt 1978; Brandt & Niedner 1987; Brandt et al. 1999).

Although this work assumes that the disconnected plasma moves away from the nucleus at constant velocity for a given DE (Voelzke & Matsuura 1998), the onsets of DEs calculated in this way are in good agreement with the onsets calculated by Yi et al. (1994b), who determined the time of disconnection by kinematic analysis assuming constantly accelerated linear motion. Although the kinematic analysis was different and the definition and classification for one DE differs a little from one author to another, the similarity of the results from these two different analyses suggests, that magnetic reconnection plays an important role in the formation of DEs and can be considered as the triggering mecanism.

The solar wind plays a major role in plasma tail DEs, which are characterized by the plasma tail being uprooted from the comet head and convected downstream in the solar wind being replaced by a new tail constructed from folding rays. The comparison of the solar wind conditions and the DEs of P/Halley's comet on 1985 December 13-14 and 1986 February 22 shows that these DEs are associated primarily with crossings of the heliospheric current sheet and apparently not with any other properties of the solar wind such as high-speed streams, dense regions, or dynamic pressure increases.

Of course better heliospheric current sheet and solar wind data, more comet images from the ground and in situ measurements from cometary flyby missions will greatly contribute our understanding of the triggering mechanism of cometary DEs.

Acknowledgements. The support obtained by M.R.V. from Fundação de Amparo à Pesquisa do Estado de São Paulo, FAPESP, under grant 98/00246-8 and from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, CAPES, under grant BEX2582/97-0, are gratefully acknowledged. The authors thank Dr. J.C. Brandt for helpful comments.

References

Barnard E.E., 1899, MNRAS 59, 354
Barnard E.E., 1920, ApJ 51, 102
Brandt J.C., 1990, Comet Halley: Investigation, Results, Interpretation 1, Mason J. (ed.). Ellis Horwood, New York, NY
Brandt J.C., Caputo F.M., Hoeksema J.T., Niedner M.B. Jr., Yi Y., Snow M., 1999, Icarus 137, 69
Brandt J.C., Caputo F.M., Yi Y., 1992c, BAAS 24, 1270
Brandt J.C., Niedner M.B. Jr., 1987, A&A 187, 281
Brandt J.C., Niedner M.B. Jr., Rahe J., 1992a, The International Halley Watch Atlas of Large-Scale Phenomena. Johnson Printing Co., Boulder, CO, University of Colorado-Boulder
Brandt J.C., Randall C.E., Yi Y., Snow M., 1992b, Asteroids, Comets, Meteors 1991, 93, LPI, Houston
Celnik W.E., Koczet P., Schlosser W., Schulz R., Svejda P., Weißbauer K., 1988, A&AS 72, 89
Delva M., Schwingenschuh K., Niedner M.B. Jr., Gringauz K.I., 1991, Planet. Space Sci. 39 (5), 697
Feldman P.D., A'Hearn M.F., Festou M.C., McFadden L.A., Weaver H.A., Woods T.N., 1986, Nat 324, 433
Hoeksema J.T., 1984, Ph.D. Thesis, Stanford University
Hoeksema J.T., 1989, Adv. Space Res. 9, 141
Hoeksema J.T., Wilcox J.N., Scherrer Ph., 1983, J. Geophys. Res. 88 (A12), 9910
Ip W.-H., 1980, ApJ 238, 388
Ip W.-H., Mendis D.A., 1978, ApJ 223, 671
Jockers K., 1985, A&AS 62, 791
Niedner M.B. Jr., 1986, Adv. Space Res. 6, 315
Niedner M.B. Jr., Brandt J.C., 1978, ApJ 223, 655
Niedner M.B. Jr., Brandt J.C., 1979, ApJ 234, 723
Niedner M.B. Jr., Brandt J.C., Yi Y., 1991, The 10 January 1986 disconnection event in comet Halley, Cometary Plasma Processes, AGU, Washington, DC, p. 153
Niedner M.B. Jr., Schwingenschuh K., 1987, A&A 187, 103
Russell C.T., Saunders M.A., Phillips J.L., Fedder J.A., 1986, J. Geophys. Res. 91, 1417
Stix M., 1989, The Sun. Springer-Verlag, Berlin, p. 228
Tomita K., Saito T., Minami S., 1987, A&A 187, 215
Voelzke M.R., Matsuura O.T., 1998, Planet. Space Sci. 46, Issue 8, 835
Wagner W.J., 1984, ARA&A 22, 267
Wegmann R., 1995, A&A 294, 601
Wegmann R., 1998, J. Geophys. Res. 103, 6633
Wu M.C., Qiu P.Z., 1987, A&A 187, 264
Wurm K., Mammano A., 1972, Ap&SS 18, 273
Yeomans D.K., 1981, The Comet Halley Handbook. An Observer's Guide. NASA/JPL
Yi Y., Brandt J.C., Randall C.E., Snow M., 1994a, AJ 107 (4), 1591
Yi Y., Brandt J.C., Snow M., Randall C.E., 1993, ApJ 414, 883
Yi Y., Caputo M.F., Brandt J.C., 1994b, Planet. Space Sci. 42 (9), 705
Yi Y., Walker R.J., Ogino T., Brandt J.C., 1996, J. Geophys. Res. 101, 27, 585
Yi Y., Walker R.J., Ogino T., Brandt J.C., 1998, J. Geophys. Res. 103, 6637