CHAPTER 3

THE TIME VARYING PLASMA PROCESSES IN THE COMA

During the perihelion passage of a comet strong interaction between the cometary plasma and solar wind occur within 2 AU from Sun. Apart from producing large ionic tails, these interactions give rise to a number of time varying plasma features such as Disconnection Events (DE), helical waves, kinks and condensations. The life time of these features vary from less than an hour to few days. In 1985-86 apparition of Comet Halley a number of such events were observed. On 13th March 1986, one such feature was observed by us. The event featured as an enhanced intensity region in the southern part of the coma in the images taken with \( \lambda 7000/175 \) Å filter (\( H_2O^+ \) emission). A \( H\alpha \) interferogram was obtained following these imagery observations. Using the interferogram a velocity map was constructed, which indicated a rapid dispersal of the feature.

Near Nucleus image of Jan 8, 1986 obtained by us and from the Nainital Observatory show the evolution of a condensation region within the coma. The condensation is distinctly observed in the blue enhanced images. From two images taken 1 hour apart, the velocity of the condensation
was found to be ~ 37 km/s in the anti-solar direction. Such features are conjectured to be the precursors of the ionic structures in the tail. Wide field photographs of 9th Jan 1986 show the tail rays evolving from a condensation region in the ionic tail. Such features called the "tail rays" can lead to DEs. The photographs of Jan 10th, 1986 show a major DE. Hence the condensation observed by us can be regarded as a potential precursor of the 10th Jan DE.

In this chapter a brief account of our observations related to the Near Nucleus plasma activity of Comet Halley is followed by a detailed discussion of the two events discussed above.

3.1 An Overview of the Near Nucleus Plasma Activity of Comet P/Halley in 1985-86

On several occasions, during Oct. 1985 to May 1986, A number of Comet Halley images were obtained in the emissions of $H_2O^+, CO^+$ and their nearby continuum. Figure 3.1 shows the selected images. Table 3.1 summarizes the observations.

On 9th and 10th Nov 1985, we had the first exposure in ionic emission lines. The emissions were found too weak to be properly recorded. However, the 9th Nov white light image shows a faint straight jet-like structure extending to ~ $10^5$ km from the nucleus, which is not seen in 10th
Fig 3.1 Comet images in $\text{H}_2\text{O}^+$ & $\text{CO}^+$ emission taken on 9 March 1986.
TABLE 3.1
Selected images for an overview study of the near nucleus plasma activity of Comet P/Halley in 1985-86

<table>
<thead>
<tr>
<th>Date</th>
<th>Filter</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985 Nov 9</td>
<td>Nil</td>
<td>$10^5$ km long jet like structure</td>
</tr>
<tr>
<td>1985 Nov 10</td>
<td>Nil</td>
<td>No jet</td>
</tr>
<tr>
<td>1985 Dec 4</td>
<td>CO$^+$, H$_2$O$^+$, Blue Cont, red cont</td>
<td>No structure</td>
</tr>
<tr>
<td>1985 Dec 5</td>
<td>&quot;</td>
<td>No structure</td>
</tr>
<tr>
<td>1985 Dec 27</td>
<td>&quot;</td>
<td>Tail visible in ionic emission</td>
</tr>
<tr>
<td>1986 Jan 13</td>
<td>&quot;</td>
<td>Tail length is more in ionic emission</td>
</tr>
<tr>
<td>1986 Mar 8</td>
<td>&quot;</td>
<td>H$_2$O$^+$ emission is stronger than CO$^+$, signature of DE is discernible</td>
</tr>
<tr>
<td>1986 Mar 23</td>
<td>&quot;</td>
<td>Fan like tail is seen</td>
</tr>
<tr>
<td>1986 April 28</td>
<td>&quot;</td>
<td>Tail not clearly seen</td>
</tr>
<tr>
<td>1986 May 8</td>
<td>&quot;</td>
<td>A kink is observable in the ionic tail at a distance of $\sim 10^5$ km from the nucleus.</td>
</tr>
</tbody>
</table>
photograph. On 12th and 15 Nov 1985, clear strong jet activities were observed. Signature of these jets are also seen on 17th Nov and the coma asymetries on 20th Nov. The photographs earlier than 9th Nov do not show appreciably the signature of the jet. From the sequence of photographs during this time, it can be concluded that the activity started around 9th Nov 1985 and repeated at an internal of ~2 days. The photographs taken in CO$^+$ emission (Jockers, 1985) and UBR bands (Liu, 1987) show the abundance of CO$^+$ ion in the jets. The cause of this event is not yet well established. As the solar activity was quite low during Nov 1985 (solar Geophysical data prompt report, 1985), the solar related cause is probably ruled out.

The photographs taken during Dec 1985 do not show any unusual feature. In early Dec (4/5) photographs the tailward elongation is discernible, whereas in late Dec (27th) photographs such elongation is not seen, even though the coma appeared to be brighter in later photographs. In the sequence of photographs, the neutral C$_2$ emission was brighter than the corresponding blue continuum whereas the ionic emission was found to be comparatively weaker.

Following a number of outbursts during the first week of Jan 1986 the cometary activity was enhanced. The white light photographs of 13th Jan 1986 show a clear tail feature. H$_2$O$^+$ and CO$^+$ images show long tails compared to their corresponding continuum images.
In the post perihelion period, we have obtained good quality photographs during the first fortnight of March, when a number of space craft encounters with the comet were taking place. In H$_2$O$^+$ and CO$^+$ images taken on 1986 March 8th, the tail could be seen up to 5x10$^5$ km from the nucleus. H$_2$O$^+$ emission was seen to be stronger than CO$^+$ emission. A dramatic DE has been observed during this time, originating at 8.8 UT at a distance of 1.3x10$^6$ km from the nucleus (Wu et al 1987). From a series of photographs (from various sources) it can be estimated that the DE front was moving in the plane of sky at a velocity of $\sim$ 35 km/s, which increased to 60-130 km/s during the following days. In the 8.8 UT the feature is expected to be seen in our photographs. Also, if the sector boundary crossing at 7.64 UT is responsible for this DE (Niedner et al 1986) and it moved at a typical velocity of $\sim$ 20 km/s, then its signature might be present in our photographs. Our photographs clearly show the branching of the tail. The DE front is not readily seen, which might have buried in the coma brightness.

Our 23/24 March 1986 data show a fan shaped tail feature with H$_2$O$^+$ brighter than CO$^+$. At this time the Comet was showing strong outburst and jet activity. The photometric observations by Gong et al (1987) at 22.9 UT show a clear enhancement of $\sim$ 4 magnitudes in several emission bands. A detailed study of the image obtained by us
would provide useful information for understanding the influence of outburst on the structures of the tail.

In April 28/29 images, the tail features were not clearly seen, whereas the coma was brighter. The 8/9 May 1986 images of coma show a narrow straight and long tail with a number of short scale structures. A helical structure within \( \sim 10^5 \) km is clearly seen.

The \( \text{H}_2\text{O}^+ \) images were taken with IHW filter at \( \lambda 7000/175 \). Hence the contribution due to the continuum is significant. However, the inferences drawn above are in comparison with the continuum images taken at \( \lambda 6840/60 \). Therefore the conclusions are not expected to change drastically.

3.2 The Optical Interferometric Observations of a Transient Plasma Structure in the Coma of Comet Halley - The 1986 March 13 event.

In this section the detailed account of the observations and data analysis of the imagery and the \( \text{H} \alpha \) interferogram obtained on 13th March 1986 event is presented following a brief review of such event on other comets. At the end, a detail discussion of the event is followed by outlining a possible theoretical model.

3.2.1 Introduction
During the perihelion passage of a comet, apart from the normal development of an extended coma, dust and ion tails, a number of less predictable events occur which provide clues about its composition and about the interaction of the cometary plasma with the solar wind. Dust jets occurring from the localized regions in the 'afternoon side' of the rotating nucleus produce non-gravitational accelerations or decelerations depending on the sense of rotation (Whipple 1950, 1951). Brightness flares of 1 to 2 magnitudes or more have been frequently reported in many comets like P/Schwassman-Wachmann 1, Morehouse 1908 III, Humason 1962 VIII (Wyckoff 1982), P/Tuttle-Giacobini-Kresak (Kresak 1974) and West 1975 n (Cosmovici 1978). Suggestions have been made that outbursts in the cometary nuclei may be caused by chemical heating, by the presence of ices more volatile than H$_2$O$^+$ or by the exothermic crystallization of amorphous ice (Donn and Urey 1957, Whipple 1980). Comets during outbursts have shown enhanced CO$^+$ emission (Greenstein 1962, Festou 1986) and it has been suggested that if a sudden phase change in H$_2$O$^+$ ice is the outburst source then strong H$_2$O$^+$ emission might be observed (Wyckoff 1982).

The cometary ion tail exhibits a variety of dynamically active structures like streamers, kinks, helices and condensations resulting from the complex interaction of the
cometary plasma with the fast moving solar wind (Brandt 1982). At times dense clouds of plasma emanate from the coma, propagate down the tail and the sequence of events can be followed for several hours (Wolf 1909). The correlations of the ionization rate with solar wind behaviour (Jockers 1985) establishes the importance of ion exchange reactions between cometary neutrals and solar wind plasma. The dramatic tail disruptions or disconnection events (DE) have been extensively observed (Bobrovnikoff 1937, Jockers and Lust 1973, Jockers 1985, Burlaga 1973, Niedner et al. 1978a, 1980, Ip 1980 and Niedner IHW Newsletter No. 9 p. 2). The occurrence of DEs have been correlated with sector boundary of the interplanetary magnetic field crossing the comet tails and a mechanism for DEs has been suggested (Brandt 1968).

3.2.2 Transient events

Apart from disconnection events which can be followed for several days, there have been reports of events even more transient. Bernard (1893) in his visual observations of the great comet of 1882 had noted transient features. Photographs of Comet Kohoutek taken on 19 January 1974 showed transient plasma features 10° away from the nucleus (Roosen 1976). Transient features lasting ~1 hour have been reported at ~50 arc sec from the nucleus along the sun-comet line of Giacobini-Zinner on several occasions (Telesco et al. 1986). The spectrophotometric observations of
Comet IRAS-ARAKI-ALCOCK 1983d between 4000 Å and 4900 Å obtained on the night of 1983 May 9/10 revealed an abrupt and dramatic brightening of the inner coma during a 20 minutes interval, preceded and followed by periods of normal stability (Lutz et al. 1986). Figure 3.2 show the temporal variability of continuum, C\textsubscript{2} emission and cm brightness of the comet during this time. Several possible mechanisms such as the outburst of ices from the nucleus and a compression wave in the solar wind enhancing the gas and dust density of the coma were invoked to explain these observations. Russell et al., (1987) have pointed out that due to the alignment of the interplanetary magnetic field with the solar wind flow, the coma could not have been shielded from the solar wind as a result of weak mass loading. This could have given rise to a Venus like interaction (Alexander et al., 1986) producing a large ionization deep inside the coma.

In its recent apparition, Comet Halley has also exhibited some transient features. Elongated jet like structures moving rapidly have been seen on blue and red images during November 1985 (Grun 1986, Jockers 1985). These observations show a large, curved, jet like structure extending 21 arc min to the south of the cometary nucleus nearly perpendicular to the projected antisolar direction. An image taken ~ 3.5 hours later shows that the direction of strongest emission had shifted by 10°. Study of the Giotto observations and the corresponding ground based
Figure 3.2. Temporal variability of comet IRAS-Araki-Alcock 1983d. It shows enhancement of continuum, C₂ and for only 30 minutes (Lutz et al 1986).
observations have also yielded short lived plasma phenomena lasting less than an hour (Ip et al. 1986). Vega I and Vega II observations of Comet Halley also show several such transient processes of short time scale. The Comet Halley observations will be discussed in detail in section 3.2.5 (A).

The digital spectra and images of Comet Halley obtained from Naismith focus of the 2.3 meter telescope at Siding Spring Observatory, Australia with a fast CCD and custom built video data acquisition system reveals a number of very rapidly time varying phenomena in terms of rapid variation (< 1") molecular emission bands. These variations belong to the inner coma region, from the core out to several minutes of arc (Ritting et al., 1986). However, these data await final analysis and interpretation.

3.2.3 Methods of observation and analysis

The observations were taken from Gurushikhar, Mt. Abu, using the imaging Fabry-Perot Spectrometer in spectrometric mode described in the section 2 of chapter II. Table 3.2 gives the comet parameters during the observations.

(A) Observations

Table 3.3 gives the journal of the observations on 13 March 1986. It was only while selecting the frames for the
### Comet parameters during observations 13. 3. 1986

<table>
<thead>
<tr>
<th>Date UT</th>
<th>AU</th>
<th>Km/s</th>
<th>AU</th>
<th>Km/s</th>
<th>V orbital</th>
<th>Parker's spiral</th>
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<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 March</td>
<td>0.98</td>
<td>-43.18</td>
<td>0.89</td>
<td>25.47</td>
<td>45</td>
<td>42°</td>
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0h UT
<table>
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<th>S.No.</th>
<th>UT of exposure</th>
<th>Exposure</th>
<th>Filter</th>
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<td>23:26:55</td>
<td>1s</td>
</tr>
<tr>
<td>3.</td>
<td>March 13</td>
<td>00:06:34</td>
<td>3m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00:09:34</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>March 13</td>
<td>00:10:17</td>
<td>5m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00:15:17</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>March 13</td>
<td>00:18:54</td>
<td>11m 06s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>00:30:00</td>
<td></td>
</tr>
</tbody>
</table>
digitization was it noticed that the frames of March 13 1986 show additional features and that the H$\alpha$ interferogram had been recorded on the same day Figure 3.3 is the white light frame wherein a projection in one direction is readily seen. Figure 3.4 and Figure 3.5 are H$_2$O$^+$ (7000 A°/175 A°) imageries of the coma taken ~ 40 minutes after the white light frame and distinctly feature the blob. The blob is at a projected distance of 2x10$^5$ km from the nucleus and occupies an extent 30,000 kmx20,000 km in the plane of the sky. The blob is seen at a position angle 160° measured North through East relative to the nucleus. In the interferogram frame at least three fringes are clearly seen. In the microdensitometric tracing fainter fringes and structures in the fringe profile can be recognised. The blob feature was shown to be definitely associated with the comet after a careful consideration of various possibilities which are detailed in Section A.1.

The details of digitisation of the H$\alpha$ interferogram, H$_2$O$^+$ and white light pictures and processing of the digitized images are given in section A.2. Figure 3.6 shows the interferogram in H$\alpha$ taken with a 5 A° bandwidth filter with an exposure of 11 minutes.

Section A.1

Association of the blob with the comet; ➔
Figure 3.3. White light frame taken at 1986 March 12.977 UT (1\textsuperscript{s} exposure). 1 mm = 8000 km.
Figure 3.4. $H_2O^+$ (7000/175 A) frame taken at 1986 March 13.006 UT (180° exposure). 1 mm = 8000 km.
Figure 3.5. H$_2$O$^+$ (7000/175 A) frame taken at 1986 March 13.0089 UT (300s exposure). 1 mm = 8000 km.
Figure 3.6. H-alpha (6563/5 A) frame taken at 1986 March 13.02 UT (660s exposure).
A detailed careful study has been made to establish the reality of the blob and to associate it with the comet.

1) An extensive search of star catalogues by us and by Dr. David Rees of University College, London (Private communication, 1987) was carried out. The star map in the path of Comet Halley, during the period March - 12 March 15, 1986 is given in fig. 3.7. Fig 3.8 shows the identification of several stars in the comet frames taken on 13th March 1986. It can be readily noted that no stellar object brighter than 11th magnitude corresponds to the blob position seen in H₂O⁺ images. It is concluded that the feature is definitely brighter than this limit and is not a compact object. Hence no stellar association with the blob is possible.

2) Search for a nebular object in the vicinity of the blob in the NGC catalogue of nonstellar objects (Sulentic and Tifft, 1973) also led to a negative result, thereby ruling out nonstellar astronomical objects down to the magnitude 16.

That the feature is not an instrumental artefact due to a possible reflection in the filters is confirmed by repeated checks of the instrument. Further

1) Out of about 200 photographs taken with similar filters, only on this occasion is such a blob feature
Figure 3.7. The star field in the path of comet Halley, during March 12-15, 1986. (Courtesy: Dr. David Rees, University College, London).
Figure 3.8. Identification of the field stars in the $\text{H}_2\text{O}^+$ frame of comet image. (Courtesy: Dr. David Rees, University College, London).
2) The region of enhanced brightness in $H_2O^+$ correlates with a feature in the white light frame where no filter was used.

3) During Dec 1985 to March 1986, at least 11 exposures were taken to obtain the $H\alpha$ interferogram of the comet. The exposure durations vary from 5 m to 60 m. No occasion except on 13th March 1986, was a $H\alpha$ interferogram obtained.

In order to identify the region of the comet to which the interferogram belongs, frame matching was carried out, using the image intensifier hot spots as the control points. After applying appropriate correction for the cometary motion, it was established that the interferogram is centred on the blob region of $H_2O^+$ image and is hence clearly associated physically with the blob emission.

As our instrument cannot record airglow [OI] 6300 emission which is ~ 100 R during our observations, the threshold can be set to > 100 R. Since the instrumental sensitivity remains same between 6300 Å to 6563 Å, the similar threshold can be used to estimate the $H\alpha$ flux. This consideration implies that the strength of $H\alpha$ emission record as interferogram is > 100 R. The $H\alpha$ flux measurement in Kerr et al (1987) given in Fig. 3.9 show that the $H\alpha$ flux at the central coma of the comet was ~
Section A.2

Digitisation and image analysis

The H$_2$O$^+$ images and the H$\alpha$ interferogram taken on photographic film were digitized with a 1010M (Perkin-Elmer) PDS microdensitometer system. The digital images have a pixel size of 20\mu m which is comparable with the intensifier resolution to produce the continuous tone image of the film. The gray level in each pixel is represented by 8 bit binary numbers and stored in a standard format (Pub No: TM 16913250, Perkin-Elmer corporation). Each horizontal scan of the image is stored as one record of the image file. An image file contains about 1000 such records corresponding to the number of horizontal scans required to complete the image. The digital images were computer processed to enhance the faint features. In order to obtain the sharp intensity gradients the local background was removed from the digital image. The median-filter algorithm with a 10x10 pixel window was used to generate a lowpass "model" of the image, representing all the largest structural information in the image. This low pass model was then subtracted from the unprocessed image to produce a highpass filtered picture. Fig.3.10 shows the isodensity contours of the H$_2$O$^+$ image. A distinct blob is clearly seen at position angle 160° (measured from north
through east) with respect to the nucleus. The blob is at a projected distance of $2 \times 10^5$ km in the plane of the sky from the nucleus. The isodensity contours of the white light image in Fig. 3.11 also show a distinctive projection (in terms of contour asymmetry) in the same region as the blob in the H$_2$O$^+$ frame. The contrast enhanced image shows that the extent of the blob in the plane of the sky is 30,000 km x 20,000 km and the peak brightness ratio of the blob to the comet nucleus is < 0.12.

(B) Velocity determination

Careful microdensitometric measurements of the fringe diameter have been made and the instrumental parameters precisely defined using He-Ne laser interferogram. A careful comparison was made with an earlier H$\alpha$ interferogram on the Orion trapezium region, which served as a celestial spectral reference of known radial velocity relative to the earth. From the measurements of the fringe shift, we obtain for the blob a recession radial velocity of 30+10 km/s relative to the comet (as seen from the earth). The interfringe separation and hence the relative velocity distribution can be better determined than the net absolute radial velocity. A procedure for determining the relative velocity distribution is detailed in section B.1. The relative velocity values are given in Table 3.4 and their spatial distribution is featured in Figure 3.13.
TABLE 3.4

Relative Radial velocity determination from line shifts

<table>
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<tr>
<th>S.No.</th>
<th>Position angle in degrees</th>
<th>Distance x10^4 km</th>
<th>Internal velocity km/s</th>
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<td>203</td>
<td>31.3</td>
<td>20±2</td>
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<tr>
<td>2.</td>
<td>200</td>
<td>28.7</td>
<td>23±2</td>
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<td>3.</td>
<td>192</td>
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<td>9±2</td>
<td></td>
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<tr>
<td>4.</td>
<td>187</td>
<td>36.7</td>
<td>10±9</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>185</td>
<td>30.7</td>
<td>23±6</td>
<td></td>
</tr>
<tr>
<td>6.</td>
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<td>-1±2</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>178</td>
<td>38</td>
<td>5±10</td>
<td></td>
</tr>
<tr>
<td>8.</td>
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<td>21±8</td>
<td></td>
</tr>
<tr>
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</tr>
<tr>
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<td>split fringe</td>
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</tr>
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<td></td>
</tr>
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<td>1±10</td>
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<td></td>
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<tr>
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<td>30</td>
<td>-6±8</td>
<td></td>
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<td></td>
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</tr>
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</tr>
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</tr>
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<td>14</td>
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<td></td>
</tr>
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<td></td>
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<td></td>
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<tr>
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<td>18.4</td>
<td>11+1</td>
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<td>158</td>
<td>19.7</td>
<td>16+1</td>
<td></td>
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<tr>
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split fringe
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<td>16</td>
<td>27+2</td>
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Figure 3.9. Variation of cometary H-alpha flux intensity during mid-March 1986. (Kerr et al. 1987).
Figure 3.10. Isophoto for $\text{H}_2\text{O}^+$ image of comet Halley at 1986 March 13.0089 UT. Contour levels are at 4, 8, 12, 32 percent of the peak photographic density.
Figure 3.11. Isophotos for whitelight image of comet Halley on 1986 March 12.977 UT. The contour levels are at 4, 8, 16 and 32 percent of the peak photographic density. The contour asymmetry corresponding to the position of the $\text{H}_2\text{O}^+$ blob in figure 10 is shown with an arrow marked circle.
3.12. Radial scans in the Halpha interferogram at angles = (a) 294°.0, (b) 0.0°, (c) 60°.0, (d) 79.5°, (e) 90.0°, (f) 97.5°, where is the angle measured at the centre of the interferogram with respect to the comet blob line extended in southern direction as 0.0°.
Figure 3.13. Doppler shift dispersion velocity distribution in the $\mathrm{H_2O^+}$ blob region. $\mathrm{H_2O^+}$ isophotes contour levels are drawn approximately from figure 10.
Section B.1

Radial scan analysis and determination of differential velocity map

In order to obtain the relative velocities of different parts of the H$_2$O$^+$ blob, a number of radial scans were taken from the centre of the interferogram and fringe shifts were measured. It is first necessary to very precisely locate the fringe centre.

Determination of interferogram fringe centre:

The digital interferogram was displayed on the image monitor and the approximate position of the fringe centre was determined by a visual inspection. Its precise location was then obtained by using a task 'IRING' of the Astronomical Image Processing System (AIPS) environment. In this task the approximate centre obtained by visual inspection, the diameter and width of the 2nd ring are given as inputs to obtain the integrated gray value of the annuli. Shifting the position of the centre to its neighbouring pixels the procedure was repeated. The pixel giving the maximum value of integrated flux of annular ring was taken as the pixel defining the centre of the FP fringe system. With this procedure the fringe centre could be determined to an accuracy of two pixels (~40 μm on the film).
Retrieval of the radial scan:

The interferogram was sampled along radial directions at various angles with respect to the horizontal reference scan. Fig 3.12 shows the example of few such scans. The record number (Y-coordinate) containing the centre of the interferogram can be directly used as one radial scan of the interferogram. Since the pixel sizes of the digital interferogram image is 20 \(\mu\)m the sampling error in this case is also 20 \(\mu\)m. However, while obtaining the radial scan along other directions the sampling error depends on the angle of the scan direction with respect to the horizontal scan. In this case the record numbers were incremented or decremented with respect to the record number of the horizontal scan and the corresponding position of the data point was calculated by specifying the desired angle. The sampling error is given by (for non-zero values of \(\theta\)):

\[
\Delta x^1 = \frac{\Delta x}{\sin \theta}
\]

Where, \(\Delta x = 20\ \text{m}\) and \(x^1\) is the sampling step in the direction defined by \(\theta\).

Velocity determination:
To obtain the wavelength corresponding to the observed radius of the fringe in the interferogram a search grid was generated to obtain a number of sets of possible radii values within the filter bandwidth.

The basic equation of the Fabry-Perot etalon is given by:

$$2 \mu t \cos \theta = n \lambda$$

.. 3.2

where $\mu t$ is the optical spacing of the etalon and $\theta$ the angle of incidence. For integral values of $n$ the constructive interference condition is satisfied and bright fringes are seen.

For a camera lens of focal length $F$, the above equation (for small $\theta$) simplifies to:

$$2 \mu t \left(1 - \frac{R^2}{2F^2}\right) = n \lambda$$

.. 3.3

where $R$ is the radius of a particular fringe.
calibration interferogram μ is estimated. A grid of radii values for the first fringe is generated using the above spacer value for slightly different wavelength around Hα and the value for the best match with the observed radius is noted. The radius for the lower order (outer) fringes were then calculated with respect to the first fringe. From equation 2 it follows that

\[ R \frac{dR}{F^2} = \frac{6\lambda}{\lambda} = V/C \]

where \( dR = R_{\text{cal}} - R_{\text{obs}} \)

Knowing the calculated and observed radius of the interference fringe pattern the relative velocity \( (V) \) of the observed Hα emission at various positions can be calculated.

Error estimation:

There are two sources of error.

(i) The effective instrumental width of 0.11 Å for the red Fabry-Perot etalon results an error in velocity estimation to 5 km/s.

(ii) The error due to sampling depends upon the
radius at which the velocity is estimated and on the
direction of the scan as defined by $\Theta$. This error is
generally more than the error due to the instrumental
limiting resolution. The errors are classified into two
zones with high and low values and indicated appropriately
in Fig. 3.13.

In addition to the determination of the velocity
structure in the blob, line profile analysis of a few bright
portion of the H$\alpha$ interferogram have also been carried out
in order to study the local dynamics of the hydrogen gas in
the blob. Figure 3.14 shows some line profiles which can be
seen to be asymmetric, indicating nonisotropic flow of the
gas in the blob. The profiles close to the blob centre are
highly structured. Least square Gaussian profiles were
fitted to the data to obtain the equivalent widths and
hence internal expansion velocities. The line profile
analysis indicates the relative velocity spread of 5 to 22
km/s in reasonable agreement with the doppler shift
velocities measured in the blob. Table 3.5 summarizes the
internal velocities obtained from the line profile analysis.
There is evidence for fringe splitting at several places in
the interferogram, which unambiguously establishes the
existence of large differential velocities in the blob.

3.2.4 Discussions
The differential velocity field derived from the Hα interferogram and the line profile measurements show a complex structure. The exact mechanism of the event is not quite clear at present. However, here we discuss the broad characteristics of the data and their implications to the understanding of the transient events in the cometary atmosphere.

(A) State of the coma activity on 13th March 1986 from other observations

As the event took place only 24 hours before the Giotto encounter with Halley the cometary coma was under close observation. Unfortunately Giotto cameras were not on at the time of the event to provide confirmation of our event. The white light images taken at South African Astrophysical Observatory at $2^h\ 32^m\ 05^s$ UT (~2.5 hours after our observations) do not show a blob. Three different jet-like structures at $65.5^\circ, 87.5^\circ$ and $102.5^\circ$ (angle with respect to sun) appearing in the E-S direction, confined to the inner coma region 20,000 to 35,000 km from the nucleus are however seen. A comparison of red filter pictures of 13th and 14th March 86 shows that the dust activity was more on 13th compared to 14th March by a factor of ~2 (Cosmovici et al., 1986). Evidence of such activity is also observable in the images taken at 0415 UT on 13 March at Catania observatory in Italy (Formisano V. et al. 1986). Dust concentration in the vicinity of the nucleus was also
<table>
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<th>S.No.</th>
<th>Position angle in degrees</th>
<th>Distance $\times 10^4$ km</th>
<th>Internal velocity km/s</th>
<th>Comments</th>
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</tr>
<tr>
<td>8.</td>
<td>204</td>
<td>30.7</td>
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<td></td>
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</tbody>
</table>
Figure 3.14. Line profiles from selected regions of the interferogram at,

(a) PA : 174°, d : 24.7  (b) PA : 140, d : 20.7

where PA : position angle and d = cometocentric distance in \( (X 10^4) \) km.
Figure 3.14. Line profiles from selected regions of the interferogram at,

(c) PA : 160°, d : 17.3 (d) PA : 135°, d : 22.7

where PA : position angle and d = cometary distance in \((x \times 10^4)\) km.
Figure 3.14. Line profiles from selected regions of the interferogram at,

(e) PA : $127^\circ$, $d : 18.0$  (f) PA : $180^\circ$, $d : 23.3$

where PA : position angle and $d = \text{cometocentric distance in } (\times 10^4) \text{ km}$.
Figure 3.14. Line profiles from selected regions of the interferogram at,

(g) PA : 200°, d : 28.7  (h) PA : 204°, d : 30.7
where PA : position angle and d = cometocentric distance in (X 10^4) km.
monitored at the 3.9 m Anglo-Australian telescope on 11th, 12th and 13th March 1986. Development of the jets over a period of 3 days could be traced in the photographs but again there is no evidence for a blob structure (Chakaveh et al. 1986).

The Ly $\alpha$ images taken at 10 h 54 m UT on 13 March do not show any asymmetry beyond $\sim 10^5$ km from the nucleus indicating the hydrogen gas flow to be uneffected by the cometary activity (Mc Coy, 1986). Photometric observations during the period 5th to 17th March 1986 show a day to day variation of intensities in several emission bands. The data show an enhancement by a factor of about two in the production rate of all observed species on 13th March compared to the neighbouring days but there are several days during the observations period when such enhancements occurred. (Schleicher et al. 1986).

Festou et al. (1986) have reported an enhanced count rate in IUE fine error sensor in 12 x 12 arc second aperture at 19 h UT on 13 March indicating an increase in the cometary visual brightness. The spectra indicate enhanced H$_2$O and CS production rates. Observations with spectral resolution at the wavelength of Hydrogen ($6563 \AA^0$) have been carried out by Kerr et al. (1987) from Arecibo-Observatory. Observations in March 86 are characterised by highly structured H $\alpha$ profiles implying nonisotropic outflow of H atoms. Velocities relative to the
comet of 35 km/s have been noted from the position of the fringe peaks. The observations for 13th March give a Hα surface brightness of 59±13 Rayleighs for a 5.9 arc minute field of view. The profile analysis show that Hα emission was confined to highly directional flow indicating the association of jet activities. From the observations discussed above we are led to the conclusion that while 13 March 1986 was a day of enhanced dust activity it was not an unusual one. The absence of the blob at other longitudes suggests that the ionic event observed by us is a transient one lasting a few hours only and that the cause is likely to be external to the comet. The few images of the comet reported over Indian longitudes on this day are on a scale too coarse for the blob to be discerned (A. Desai et al. 1987, A.K. Bhatnagar 1987 - Private communications).

However, there appears to be some evidence for transient ionic features lasting ~ 1 hour in the inner coma of Comet Halley. A comparison of ground based SAAO CCD H₂O⁺ observations with the Giotto NMSE and IMSE measurements of Comet Halley reveals such an activity in the comet. These instruments on Giotto had recorded a plasma pile up region at ~ 10⁴ km from the nucleus which should have showed up in the ground based CCD images as inhomogeneous structures. The clear absence of such structures in the CCD images suggests their rapid time variability ~ 1 hour (Ip et al. 1986).

In the case of Vega-1 encounter, the SDA sensor observed
a burst of ions with energies ~ 100-1000 ev near the closest approach to comet Halley lasting ~ 5 minutes. Based on the magnetic field observations in the path of the spacecraft (Verigin et al, 1987) it was concluded that the burst was produced by the motion of cometary ions of water-group accelerated up to superalfvenic speeds ~ few tens of km/s. Further they point out that the acceleration could be caused by merging of interplanetary magnetic field lines of opposite polarity retarded by the presence of cometary plasma and neutrals. Figure 3.15 describes the topology of the magnetic field around closest approach as deduced from the measurements of the magnetic field direction (the arrows) along the Vega-1 trajectory. The dotted area in the figure represents the region in which the bursts of accelerated ions was observed. Such observations of well-defined intensity enhancement of ions with energies > 40 kev are reported from Tunde-M experiment on board Vega-1 (Somogyi et al 1986).

The theoretical studies have shown several possible explanations for such outbursts in the cometary ionosphere (Delsemme 1979). The rapid ionization of the gaseous material in the coma can be achieved by the discharge of cross tail electric current. Such ionization surge, well within the coma, can also be caused by electron jetting in the reconnection current sheet which is produced by the passage of an interplanetary sector boundary through the comet (Niedner 1980).
Figure 3.15. Topology of the magnetic field around the closest approach as deduced from the measurement of the magnetic field direction (the arrows) along the Vega-1 trajectory. The burst of accelerated ions was observed in the dotted area (Vergini et al 1987).
(B) State of the interplanetary magnetic field

Since it is conjectured that the observed event could be a special type of disconnection event caused by the passage of an interplanetary Magnetic field boundary through the comet it is pertinent to enquire about the state of the interplanetary magnetic field at the time of the event.

Comet Halley was predicted to enter a current sheet warp at about the time of the Japanese cometary space probe Sakigake's encounter on March 11, 1986 and to exit from it two days later (Niedner 1986). The observations from Sakigake and Giotto show that it was indeed the case (Saito et al., 1986, Neubauer et al., 1986). The multiple crossing of the current sheet by the comet during March 11-14, 1986 was clearly evident from Sakigake's measurements, which located the sector boundary at 7x10^6 km upstream of Comet Halley. It is known that only if comet penetrates the sector boundary perpendicularly can major ionic tail disconnection events take place (Niedner et al., 1978). However, since no major DE was observed during this period, Saito et al (1986) proposed that the crossing of the sector boundary by the comet was quasi-parallel as shown in figure 3.16. The Sun-Comet-Earth geometry and the Parker's spiral at the time of our observation is given in Fig.3.17. Since the comet was
Figure 3.16. The quasi-parallel crossing of the sector boundary by comet Halley (Saito et al. 1986).
Figure 3.17. Sun-Comet-Earth Geometry and the interplanetary magnetic field structure during observations.
crossing the ecliptic plane at this time, sun, comet and earth can be considered to be in the same plane. According to Saito et al. (1986) the comet crossed the neutral sheet at a small attack angle. Considering the motion of the comet, they pointed out that, the southern part of Halley dipped first into the away sector, changing the polarity of the field line from towards to away polarity. Though the authors argue that the gradual reconnections of field lines may not lead to a drastic DE, no quantitative picture is outlined.

Further if the radial alignment of the field occurred at that time the inner region of the coma could not have been shielded from the solar wind flux, which could have led to an enhanced ionization as in the case of Venus and Comet IRAS-ARAKI-alcock (Russell et al., 1987). The time scale of ionization by these processes are found to be very short ~ 10³-10⁴ s.

Qualitatively the geometry of the reconnecting magnetic fields can be represented in Fig. 3.18. Here, the magnetic field lines of reversed polarity flow towards each other at a relative velocity in the Z-direction, are cut in the diffusion region (the hatched area) and the reconnected field lines flow out of the diffusion region in + x-direction. The $\mathbf{j} \times \mathbf{B}$ driven electron jets in the reconnection current sheet would then produce sufficient energy to create a rapid ionization region.
Figure 3.18. Geometry of reconnecting fields just before a disconnection event (DE). The direction of plasma outflow from the diffusion region (shaded) is given by $V_A$. 
(C) Kinematics of the blob:

The relative radial velocity measurements show a complicated velocity field as represented in fig.3.13. However, dividing the map into high and low velocity zones, it can be noticed that the velocities are clustered into compact regions. There are some zones of high relative velocity. A number of split fringes are also seen especially on the Sunward side. The velocity distribution around the blob is also not symmetrical, indicating thereby that the expansion of the blob is not simply governed by the diffusion process.

(i) Estimate of time of dispersal

Assuming the surface brightness of a spherical blob to vary as $1/r^2$ and an isotropic constant expansion velocity of 30 km/s it is possible to estimate crudely the time taken ($\Upsilon$) by the blob intensity ($I_0$) to reach the background sky level ($I$). The time of dispersal of the blob is given by:

$$\Upsilon \approx \frac{R_0}{V} \sqrt{\frac{I_0}{I}}$$

For $I_0/I \sim 8.1$ and $2R_0 \sim 3 \times 10^4$ km and $V \sim 30$ Km/s, $\Upsilon \sim 23$ minutes.
A slowing down of the dispersal velocity would result in a longer period of visibility. However, it is unlikely that the blob will survive for more than a few hours. The short life span can explain the lack of sightings of the blob by groups located at other longitudes.

(ii) Mass:

Assuming the blob to be spherically symmetric to a first approximation, with a $2 \times 10^{22}/r^2$ (cm) dependence of $H_2O^+$ number density we estimate the mass of the blob to be

$$\int 4 \pi n(H_2O^+)r^2 dr = 10^{10} \text{ g}$$

Extent of the blob

3.2.5 A theoretical model for the event

Based on the knowledge that a sector boundary crossing had taken place during the time of the event, a theoretical model for the formation and movement of the blob is suggested below.

The plasma tail disconnection events in Comets are believed to be caused by magnetic reconnection which occurs due to the passage of a sector boundary through the
cometary head \cite{Niedner and Brandt 1978,1979,1980}. One of the consequences of the magnetic reconnection is that plasma flows out of both sides of the reconnection region at the Alfvén speed as shown in fig. 3.18. We propose that the ejection of $\text{H}_2\text{O}^+$ blob observed by us on 13th March is caused by magnetic reconnection in a way as described in fig. 3.15. The blob during its outflow in the solar wind is constrained by the pressure balance equation:

$$\frac{B_c^2}{4\pi} \left( \frac{R_o}{R_s} \right)^2 + \int_c \left( \frac{R_o}{R_s} \right)^2 v_c^2 = \int_s v_s^2$$ \ldots 3.7

Where $\int_c$ is the blob density at $R_o$ and is assumed to vary as $r^{-2}$; $B_c$ is the magnetic field at $R_o$ and is assumed to vary as $r^{-1}$; $v_c$ is the outflow velocity which is close to Alfvén velocity $V_A$ in the Cometary head and is assumed to remain constant; $R_o$ is the initial position of the blob, measured from the nucleus. $\int_s$ and $v_s$ are the density and velocity of solar wind and $R_s$ is the observed separation of the blob from the comet head in the $\text{H}_2\text{O}^+$ frames. Magnetic field of the solar wind is taken to be much smaller than the Cometary magnetic field and is neglected.

From equation (1), one finds:
The time $\tau$ taken for the blob to reach $R_s$ is given by:

$$\tau = \frac{R_s - R_0}{V_A}$$  \hspace{1cm} \ldots 3.9$$

From the measurements made by Vega space missions to Comet Halley it follows that the number density of $H_2O^+$ ions at a distance of $\sim 10^4$ km from the nucleus has a value $\sim 3 \times 10^3$/cc. and varies approximately as $1/R^2$ where $R$ is the distance to the comet nucleus. The plasma convective velocity estimates imply a velocity 2-3 km/s at $\sim 10^4$ km which rises to $\sim 20$ km/s at $\sim 2 \times 10^5$ km, the distance from the nucleus at which the $H_2O^+$ blob is seen ($R_s$). (Vaisberg et al., 1987).

Putting in the values $V_A \sim V_c \sim 20$ km/s,

$V_S \sim 450$ km/s $\int_s \sim 1.7 \times 10^{-25}$ g/cc (10 solarwind protons/cc)

$\int_c \sim 10^{-19}$ g/cc.
We get \( R_0 / R_S = \left( \frac{f_p}{2f_c} \right)^{1/2} \frac{V_S}{V_A} \sim \frac{1}{5} \).

Therefore the initial position of the blob should be 4x10^4 km from the nucleus. The time taken by the blob to reach the position \( R_S \sim 2 \times 10^5 \) km is given by

\[
\tau = \sqrt{\frac{R_S - R_0}{V_A}} \sim 2.2 \text{ hours}
\]

The cometary magnetic field at the initial position \( R_0 \) is \( \sqrt{4 \pi P_c} V_A \sim 200 \gamma \) and at \( R_S \) is \( \sim 10 \gamma \).

The cometary magnetic field \( B_c \) may appear to be rather high but is not unacceptable especially when the field is expected to undergo compression in the cometary head. Thus plasma outflow caused by magnetic reconnection provides a reasonable description of the \( H_2O^+ \) blob.

3.2.6 Summary and Conclusion

Fabry-Perot interferometric observations along with the \( H_2O^+ \) emission imagery data taken at \( \sim 0^h \) UT on 13th March
1986 reveal a transient ionic activity in the coma of Comet Halley.

1) A distinct extended brightness region (blob) in the $\text{H}_2\text{O}^+$ image is clearly seen at position angle $160^\circ$ relative to the nucleus at $2 \times 10^5$ km projected distance in the plane of sky.

2) A $\text{H}\alpha$ interferogram is recorded in the region of $\text{H}_2\text{O}^+$ blob. Interferogram analysis shows:

   (i) The blob has a recession radial velocity of $\sim 30 \pm 10$ km/s relative to the comet (as seen from the earth).

   (ii) Gaussian analysis of the line yields Doppler line width velocities from 5 to 22 km/s (Fig. 2.14)

   (iii) The relative differential velocity map exhibits a structured distribution. High velocity and low velocity regions are clustered. Fringe splitting is observed at many places on the Sunward side.

   (iv) The dispersal time at the blob is estimated to be approximately $\sim 30$ minutes. The event is definitely a transient one.

3) An upper limit to mass of the blob should be $\sim 10^{10}$ g.
4) Comet was crossing the interplanetary sector boundary at about the time of the observations. An explanation of the event has been attempted from the state of the interplanetary magnetic field geometry in the vicinity of the comet. Our event appears at a time when disconnection events are most expected. However, it occurs in a region of the coma and not in the ionic tail wherein are triggered the normal disconnection events. The direction of the blob movement and its duration are unlike a typical disconnection event. This event appears to be triggered by nuclear activity in combination with the current sheet crossing.

In conclusion, we would like to stress on the need for close monitoring of a comet, particularly in the ionic emissions like $\text{H}_2\text{O}^+$ or $\text{CO}^+$ during its period of maximum activity to ensure that the transient events like the one reported here are not missed out. Such events by many observers can provide valuable insights into this intriguing aspect of cometary behaviour and the interrelationship with the interplanetary medium.

3.3 The Plasma Condensation Region in the Coma of Comet Halley Observed on 8th Jan 1986.

The recent observations of Comet Halley and the advent
Image Processing techniques have shown that the coma is far from homogenious and isotropic. Straight plasma jets and spiral dust jets are often seen in the near nucleus region. The processed images of the comet in molecular and atomic emissions have clearly shown that these species follow the spiral trajectory in the inner coma region (A' Hearn et al 1986, Cosmovici et al 1988). The collimated flow of atomic hydrogen is inferred from Fabry-Perot observations (Kerr et al., 1987). Several plasma structures, in terms of enhanced brightness in the coma region (Ip et al 1987) in the ground based imaging observations and enhanced electron or ion density (Ip et al 1987) from the in-situ measurements have been inferred in Comet Halley.

Some of these ionic features observed in the near nucleus of the coma region are expected as the precursor of several fine features observed in the ion tail of comets. For example Wurm et al (1967) could successfully trace the ray structures within $10^3$ km from the nucleus. One of the most distinguished features, widely observed in the tail are the condensation regions, which appear as the confined enhanced bright clouds moving in the down stream of the tail. Extensive work on Comet Kohoutek by Jockers (1985) showed that these features move at an average speed of $69\pm27$ km/s within $5\times10^6$ km and $90\pm29$ km/s outside. Further he pointed out the evidence that at least some tail condensations originate in and or expelled from the coma region with a speed of $\sim20-40$ km/s. These numbers agree
qualitatively with the velocities obtained for other comets (Vsyekhsyatskii and Demenko 1976, Jockers et al. 1972, Miller 1969, Lust 1967, Ahnert 1943). However the motion of such features depend on specific situation in which they are produced and controlled by magnetic field configuration. The mechanism of formation of such features are expected to be at a relatively shorter time scale as deduced from the observations (Eddington 1910, Wurm 1963).

Our short exposure, high spatial resolution imaging data of Comet Halley taken on 1986 January 8.59 and 8.632 UT show such a feature at a distance of $2.4 \times 10^5$ km from the nucleus, moving at a mean speed of $\sim 36.5$ km/s. A similar image taken from Nainital Observatory also shows the signature of the feature. CCD images taken in CO$^+$ and H$_2$O$^+$ emission by Michael A'Hearn show long jet like structures in the coma and in the tail region. The sequence of wide angle photographs taken on 10th January 1986 show a "dramatic" DE starting at 10.375 UT, whose roots can easily be traced on to the 9th January images.

In this section the observation and analysis of the data apparently related to 10th January DE obtained by us, is presented. A possible mechanism of its formation is outlined. The relation of the observed condensation with the tail activity is discussed in detail.

3.3.2 Methods of observation and Analysis of Jan 8 →
The observations were taken from Gurushikhar, Mt. Abu, using the imaging Fabry-Perot instrument in imaging camera mode described in section of the chapter II. Table 3.6 gives the comet parameters during the observations.

(A) Observations:

Table 3.7 gives the Journal of observations on 8 January 1986. The data obtained by us consists of two white light images taken through a Fabry-Perot etalon having high reflection coatings for the wavelength region 5700 Å to 6700 Å. Consequently the transmission is high in the blue region. The blue enhanced white light images are therefore expected to be sensitive to CO$^+$ emission at 4260 Å. One image was taken through the above etalon with a Kodak Wratten filter No. 25 which is characterized by transmission longward of λ 5900 Å. A white light image taken with a 102 cm telescope was procured from U.P State Observatory, Nainital. The CCD images of the comet in ionic emission lines have been kindly provided by Michele F A'Hearn. Table 3.8 summarizes the data base.

The blue enhanced images distinctly show the condensation region of size $\sim 10^4$ km at a distance of $\sim 10^5$ km from the nucleus.
TABLE 3.6

Comet parameters at the time of observations

<table>
<thead>
<tr>
<th>Date</th>
<th>RA</th>
<th>Dec</th>
<th>$\Delta$ RA</th>
<th>$\Delta$ Dec</th>
<th>$\Delta$ AU</th>
<th>$\Delta$ Km/s</th>
<th>R</th>
<th>$\dot{R}$ Km/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN 8</td>
<td>2158.553</td>
<td>-411.891</td>
<td>-1.3'/hr</td>
<td>0.53'/hr</td>
<td>1.29</td>
<td>30.43</td>
<td>0.9</td>
<td>-25.64</td>
</tr>
</tbody>
</table>
**TABLE 3.7**

**Journal of Observations**

<table>
<thead>
<tr>
<th>UT</th>
<th>Exposure time</th>
<th>Filter</th>
<th>Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN 8.590</td>
<td>$10^8$</td>
<td>Blank</td>
<td>2415</td>
</tr>
<tr>
<td>JAN 8.595</td>
<td>$120^s$</td>
<td>25</td>
<td>2415</td>
</tr>
<tr>
<td>JAN 8.638</td>
<td>$10^8$</td>
<td>Blank</td>
<td>2485</td>
</tr>
</tbody>
</table>

*Kodak emulsion.*
The data base for the study of 8th Jan 1986 event

<table>
<thead>
<tr>
<th>Date (UT)</th>
<th>Exposure time</th>
<th>Filter</th>
<th>Film</th>
<th>Remarks</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 8.124</td>
<td>-</td>
<td>CO⁺</td>
<td>CCD</td>
<td>Strong ray structure</td>
<td>Yuman Observatory, China</td>
</tr>
<tr>
<td>January 8.582</td>
<td>5 m</td>
<td>-</td>
<td>IIa-o</td>
<td>Tracking not good</td>
<td>UPSo Nainital.</td>
</tr>
<tr>
<td>January 8.590</td>
<td>10ˢ</td>
<td>Blank</td>
<td>2415</td>
<td>Condensation seen</td>
<td>Physical Research Laboratory</td>
</tr>
<tr>
<td>January 8.595</td>
<td>120ˢ</td>
<td>Kodak 25</td>
<td>2415</td>
<td>No condensation seen</td>
<td>&quot;</td>
</tr>
<tr>
<td>January 8.638</td>
<td>10ˢ</td>
<td>Blank</td>
<td>2485</td>
<td>Condensation moved in the antisolar direction</td>
<td>&quot;</td>
</tr>
<tr>
<td>January 8.94</td>
<td>-</td>
<td>Blank</td>
<td>IIa-o</td>
<td>A strong kink is seen in the antisolar direction</td>
<td>Yuman Observatory, China</td>
</tr>
</tbody>
</table>
The blob is absent in the red enhanced image taken with Kodak Wratten filter 25. The white light image obtained from UPSO, though not of good quality, shows the signature of the condensation in terms of asymmetric distribution of enhanced brightness in the outer coma region. The CCD images of A'Hearn, taken in CO$^+$ emission show strong rays in the direction of the condensation. Fig. 3.19 show the images mentioned above.

(B) Identification of the condensation

A careful study has been made in order to establish the reality of the condensation and its association with the comet. The investigation in this case is relatively straightforward since the bright stars are registered in all the cometary images obtained with various instruments. Comparing the star field of the comet frame obtained by us and from UPSO, Nainital (Fig. 3.19), it is clear that 6 bright stars are common to both the frames and these 6 stars are not the artifact of the instruments used. Therefore, if we consider the condensation recorded by us is a ghost image of the Cometary Nucleus (because of the internal reflection), we must get similar reflected ghost images of the bright field stars (as the star brightness are more than that of cometary nucleus). Since in our comet frames we do not see the ghost images of the stars, we do not consider that the observed condensation is a ghost of the Cometary Nucleus. Extensive search of star catalogue and the NGC catalogue of
Figure 3.19a. White light photograph of comet Halley taken on 1986 Jan 8.590 UT. (2415 Kodak film). Scale 1 mm = \( 1.1 \times 10^4 \) km.
Figure 3.19b. Photograph of comet Halley taken with a Kodak 2.5 Wratten filter on 1986 Jan 8.595 UT (2415 Kodak film). Scale 1 mm $= 1.5 \times 10^4$ km.
Figure 3.19c. White light photograph of comet Halley taken on 1986 Jan 8.638 UT (2485 Kodak film). Scale 1 mm = 1.5′ x 10 km.
Figure 3.19d. White light photograph of comet Halley taken on 1986 Jan 8.5% UT at UP State Observatory, Nainital.

Scale 1 mm = 3 x 10^4 km.
non stellar objects was made in order to assure that the feature is not due to any other astronomical object in the plane of sky with the observed field of view. Thus we are lead to the inescapable conclusion that the condensation region belongs to the Comet Halley.

(C) The velocity determination:

As a first step, the relative coordinates of the stars in the frame, Comet Nucleus and the centre of the condensation region were measured with a Zeiss film reader. Finally the accurate positions were determined using a microdensitometer with an uncertainty of 3" (~3000 km). The frames taken at an interval of 1^h, showing the condensation, were matched taking the field stars as control points. The comet was moving in the plane of sky at a rate of -1.3'/hr in RA and +0.53'/hr in Dec. The resultant displacement of the comet in one hour is 1.4' in the North-West direction making an angle 21° to the West. This is represented in Fig. 3.20. The second image of the comet with respect to the stars was indeed found to show the displacement relative to the first image by 1.4 and in the North-West direction. The superimposed (with respect to star field) frame is illustrated in Fig. 3.21. In order to find the net velocity of the condensation with respect to the comet, the Cometary motion has to be corrected. Hence the comet position in the 2nd frame was displaced so as to match with the position in the 1st frame. The position of the condensation was also
Figure 3.20. The motion of the comet in the plane of sky at the time of our observations on 1986 Jan 8.
Figure 3.21. The sketch of superimposed comet frames taken at 8.590 UT and 8.638 UT. Only stars are matched.
displaced by same amount in the same direction. Fig. 3.22 show the superimposed comet images. A similar exercise was also carried out with the UPSO photograph. The distance of the condensation region at different times with respect to the Nucleus was determined as given in table 3.9. The velocity determined from the displacement of the condensation in the plane of sky was corrected for the orientation of the anti-solar direction in the sky. The velocities (corrected or uncorrected) are also given in table 3.9.

(D) Determination of the size of the condensation:

The brightness profiles of the comet and the condensation in different directions from the nucleus were obtained by taking microdensitometry scans, using a slit of height 5700 km and width 1400 km at the comet. Fig. 3.23 shows two brightness profile of the comet are along the direction of condensation and the second in the direction from the nucleus. The average width of the condensation region (10% above the background) is ~ 0.7 mm on the film, corresponding to ~ 4x10^4 km at the comet. The intensity ratio of the peak brightness of the condensation to the neighbouring coma region is ~ 1.8.

(E) The emission from the condensation:

The condensation region was seen only in those images
TABLE 3.9

Velocity of the condensation

<table>
<thead>
<tr>
<th>UT</th>
<th>$x10^5$ km</th>
<th>km</th>
<th>km/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN 8.590</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAN 8.638</td>
<td>3.0</td>
<td>$12x10^4$</td>
<td>28±3 km/s</td>
</tr>
<tr>
<td>JAN 8.940</td>
<td>6.8</td>
<td>$38x10^4$</td>
<td>17±5 km/s</td>
</tr>
</tbody>
</table>
Figure 3.22. The sketch of the superimposed comet images. In the diagram the centre of the comet in two frames taken at 8.590 UT and 8.638 UT are made coincident. The net displacement of the condensation is evident.
Figure 3.23. The brightness profiles of the comet along the condensation and in the opposite direction.
of the comet, which were blue enhanced by using a red FP etalon. The images taken with a Kodak wrattern filter-25 which is a high pass filter at 5900 Å do not show the feature. Though the signature of the condensation is evident in the white light image, it is not distinctly seen. This suggests that the brightness of the feature was mostly in blue region.

The velocity determination show that the condensation was moving at \( \sim 37+5 \) km/s. It is difficult to conceive the motion of the neutrals at such high speed.

It is observed on other occasions that such features are bright in ionic emission lines. For example the photographs of Comet Halley taken with a focal reducer instrument in \( \text{CO}^+ \) and \( \text{CO}_2^+ \) emission lines on 1986 April 11.11 UT clearly show a confined plasma cloud moving in the anti-solar direction (Jockers et al 1987). These observations precede the outstanding DE at 11.33 UT. The plasma cloud was seen at a distance of \( \sim 5 \times 10^4 \) km from the nucleus. Several narrow rays were seen to originate from this cloud. The multislit spectra taken by the same author on 10th April show that in blue region \( \text{CO}^+ \) is the prominent ionic emission. \( \text{CO}_2^+ \) and \( \text{OH}^+ \) also emit in the wavelength region below 3700 Å.

The condensation observed by us is followed by an outstanding DE of 10th Jan. The \( \text{CO}^+ \) images taken with a CCD
by Dr. A'Hearn show the long straight ray structures in the same direction as the motion of the condensation region observed by us. Hence the rays can be regarded as having originated from this condensation. Hence the event observed by us appears to be similar to that of 11 April observations. It can therefore be inferred that the condensation mostly consists of ionic material. CO$_2^+$ and OH$^+$ emissions fall beyond the spectral sensitivity of the image intensifier used by us but not CO$^+$ (4260 Å). These considerations lead to the conclusion that the emission from the condensation is mostly due to CO$^+$ ions.

(F) Ionization time scale

The excess ions in the condensation region must have been formed due to an anomalous ionization mechanism operating on a short time scale. If the time scale of the ionization mechanism is $T$ and if the velocity of the ions produced is $V$ then the maximum extent of the ionization region $d$ can be expressed as;

$$d = VT$$

...3.12

Hence the upper limit of the ionization time scale can be expressed as $T < d/V$. 
Assuming that the particles of the condensation region have the same velocity as determined from the motion of the feature i.e. ~ 37 km/s, the ionization time scale can be estimated as ~ 1.1x10^3 s. However, even if the thermal velocities of the ions i.e. ~ 5-7 km/s are considered as the ion velocity within the condensation, the ionization time scale cannot exceed 10^4 s. Therefore it is concluded that the condensation region is the resultant of a rapid ionization process lasting for ~ 10^3 - 10^4 s.

3.3.3 Discussion


In early January 1986 Comet Halley was active and showed complex jet features almost every day including some northward jets and antisunward jets as shown in Fig. 3.24 (Larson et al 1987). Watanabe et al (1987) have reported the major jet activity in the coma of the comet particularly on 8th Jan 1986. Due to the jet activity the near nucleus contours are expected to be distorted. The ratio of the semimajor axis to the semiminor axis i.e. R_{AB} would then represent the degree of jet activity. Watanabe et al have plotted R_{AB} as a function of days in Dec. 1985 and Jan. 86, which is reproduced in Fig. 3.25. The maximum activity on
Figure 3.24. The jet activity of the inner coma of comet Halley in the early January 1986 (Larson et al 1986).
Figure 3.25. Day to day variation of the axial ratio $R_{AB}$ which indicates the activity of jets (Watanabe et al 1987).
8th Jan 1986 can be clearly noticed from this diagram. In the first week of Jan 1986, the nuclear activity in the Comet Halley was episodic with cycles of roughly two days (Larson, 1986). The outburst recorded in optical CCD images on January 6.1 UT at Catalina Observatory show complex curved sunward jets and a bright linear antisolar jet. The IR observations on January 8.1 UT (Tokunaga 1986) show the brightness excess of ~ 30% compared to the neighbouring days. During these events an excess amount of the gas along with the dust must have been released. In order to estimate the production rate of CO released on 8.1 UT, $Q_{\text{CO}}$ was plotted as a function of heliocentric distance. Assuming that during the outburst observed in IR, a similar amount of excess gas must have released, the production rate can be estimated as $Q_{\text{CO}} \approx 2.3 \times 10^{29} / \text{s}$.

The anisotropy created due to these outbursts, however, cannot propagate to the outer coma region to a distance of ~ $10^5$ km from the nucleus (Kolem et al 1986). Hence though the above discussion show that the comet was active during our observation, the observed condensation seems to be distinctly different from the jet activities or the nuclear outbursts. The ray structures observed in the ionic tail during this time are very strong. Fig. 3.26 shows the strong ray structure in the CCD images of the comet taken in CO$^+$ emission. It is possible that the root of the ionic ray structure seen in Fig. 3.26 is the condensation region observed in the images obtained by us.
Figure 3.26. Strong ray structures in the wide field photographs of comet Halley taken in CO$^+$ emission band (Courtesy M.A'Hearn, University of Maryland, USA).
(a) Taken on 1986 Jan 8, 02h:05m UT
(b) Taken on 1986 Jan 8, 02h:29m UT
(c) Taken on 1986 Jan 8, 03h:03m UT.
(B) The source of ionization:

Identification of the correct ionization mechanism of the short time scale required \((10^3-10^4 \text{s})\) is a difficult task and often it is not uniquely determined for a single observation. For example the photoionization, solar wind charge exchange reactions, "internal" mechanisms (e.g., Ip and Mendis 1975, 76) and gas phase reactions (Oppenheimer 1975) have been proposed and all are more or less still under consideration today, as possible ionization sources. Perhaps they all occur but in different regions of the coma. Table 3.10 gives various possible ionization mechanism for CO and their time scale. In this section the short time scale ionization mechanisms is discussed in order to investigate an appropriate ionization source producing the observed condensation.

B.1 Alfven mechanism:

It was proposed by Alfven (1954, 60) that if the neutral gas and magnetized plasma are in a relative motion with a velocity exceeding a critical value \(V_c\) than an anomalous ionization mechanism only can reduce the speed of relative motion. In such cases, some hypothetical collisionless interaction between the plasma species triggers the energy flow to electrons via plasma waves, thereby ionizing the
### TABLE 3.10

*Time Scale of Possible Ionization Mechanism*

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Time scale (sec)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Photo ionization</td>
<td>( \sim 8 \times 10^5 )</td>
<td>Fernandez et al (1983)</td>
</tr>
<tr>
<td>2. Charge exchange</td>
<td>( \sim 1.6 \times 10^6 )</td>
<td>Ip (1985)</td>
</tr>
<tr>
<td>3. Electron impact</td>
<td>( \sim 4.5 \times 10^7/\text{ne} - 6.0 \times 10^7/\text{ne} )</td>
<td>Ip (1985)</td>
</tr>
<tr>
<td>4. Alfven Mechanism</td>
<td>( \sim 10^4 - 10^5 )</td>
<td>Formisano et al (1982)</td>
</tr>
<tr>
<td>5. Discharge of crosstail</td>
<td>( \sim 10^3 - 10^4 )</td>
<td>Ip and Mendis (1975, 1976)</td>
</tr>
<tr>
<td>7. Gasphase reactions</td>
<td>( \sim 10^4 )</td>
<td>Openheimer (1975)</td>
</tr>
</tbody>
</table>

\( \text{ne} \rightarrow \text{Electron number density} \)

The critical velocity is given by,

\[ V_c = \sqrt{\frac{Ze\phi}{m}} \]

\[ = 12.6 \text{ km/s for CO} \]

where \( m \) = mass of the neutrals, \( \phi \) = ionization potential of the species under consideration. The detailed theory of critical velocity ionization (CVI) mechanism in the cometary atmosphere was developed by Formisano et al (1982). The collisionless transfer of the fraction of the particles kinetic energy for ionization of the neutrals is the crucial part of CVI process. The efficiency \( \eta \) is defined as,

\[ V_c = \eta^{1/2} \sqrt{\frac{Ze\phi}{m}} \]

Formisano et al (1982) have also shown that the efficiency of energy transfer in a varified gas turns out to be very low i.e. \( \eta = 0.025 \) and reaches a relative high value \( \eta = 0.67 \) only in a sufficiently dense gas. The Townsend condition for avalanche ionization of the gas, restricts the region of anomalous ionization of cometary gas to the inner part of the coma. The same authors have
also shown that for the production rate of \( \sim 2 \times 10^{29} \) molecules/s the ionisation efficiency smoothly changes from 0.025 at a distance \( > 3 \times 10^4 \) km to the value 0.67 at \( r < 1.5 \times 10^3 \) km, where the approximation of dense gas is valid. As discussed earlier, the gas production rate for CO i.e. \( Q_{\text{co}} \) during the time of our observations was \( \sim 2.3 \times 10^{29}/s \).

Hence assuming that the ionization might have taken place within \( \sim 10^4 \) km from the nucleus, it is required that the relative velocity between the neutral and plasma component in this zone must exceed the critical velocity. The spacecraft measurements show that the plasma velocity within \( 4 \times 10^4 \) km from the nucleus is mostly \( \sim 3-7 \) km/s (Schwenn R 1987) which is much lower than the critical velocity. Therefore it is unlikely that the mechanism can produce ionization in condensation region discussed here.

However, Galeev et al (1986) have shown that in the presence of the plasma instabilities of high growth rate, CIV mechanism can be effective, giving rise to some features observed by vega-2. A detailed analysis of the electron energy, magnetic field and the particle velocity data from several spacecrafts is still awaited for reaching a firm conclusion.

B.2 Current disruption:

It was proposed for the case of earth's magnetotail
that, a cross tail current system with a current sheet separating two tail regions of opposite magnetization should be present (Nees 1965). This process was also observed in the simulation experiments performed by Podgorny et al (1979). In the case of comet, if the structure of the magnetic field and the electric current in the cometary tail type I can be represented by an electric current circuit, the disruption of the cross-tail current system may lead to a current discharging through the cometary ionosphere and the dissipation of the magnetic energy stored in the tail. These are called the "cometary aurora" events, which might be the source of hypothetical internal ionization sources as advocated by Wurm (1963). It is also pointed out that even if only 25% of the cross tail current of energetic electrons (~1-10 Kev) were to close through the cometary head it could cause rapid ionization in the inner coma with a time scale of, as small as ~5x10^3 s.

As proposed by Ip et al (1976), the model cross-tail current system with an electric field E acting across the tail aligned magnetic field $\vec{B}_t$, can be represented as in Fig. 3.27. If the tail-aligned field is $\vec{B}_t$, the current density $j$ in the current sheet is given by the Maxwellian relation

$$\vec{\nabla} \times \vec{B}_t = \frac{4\pi j}{c}$$

...3.15
Figure 3.27. The model of cross tail current system with an electric field $E$ acting across the tail aligned magnetic field. The resulting $\mathbf{J} \times \mathbf{B}$ force will act in such a way that the ion tail plasma are accelerated tailwards $B_t$. (Ip et al 1982).
under steady conditions. The sheet current density integrated through the thickness of the current sheet \( \text{Ln} \) then will be,

\[
\frac{j_s}{4} = \frac{CBt}{4}
\]

...3.16

and the total cross tail current flowing through the central current sheet may be estimated to be,

\[
I_t = \frac{C}{4\pi B_t L_t}
\]

...3.17a

where \( L_t \) is the length of the ion tail. If the total cross tail current \( I_t \) is expressed in Amperes, the tail-aligned magnetic field \( B_t \) in gamma (1 gamma = 10^{-5} Gauss) and the total length of the tail carrying the current \( L_t \) in km, then

\[
I_t = 1.6 B_t L_t
\]

...3.17b
The total length of the plasma tail on 8th Jan 1986 estimated from Fig. 2.28 in \( L_t \sim 10^7 \) km. Taking \( B_t \sim 80 \) V, which is a typical value obtained from spacecraft measurements, the total current is \( \sim 1.3 \times 10^9 \) A.

When the disruption of the tail current estimated above takes place, there could be field aligned current discharging through the cometary head as shown in Fig. 3.29. Such transient effects are expected to accelerate the charged particles and consequently energize them to Alfven energy of a few Kev. Under these circumstances the effective (anomalous) resistivity will increase well above the classical value as shown experimentally by Hamberger et al (1970). This would lead to instabilities in a finite resistivity current sheet pinch. The detailed calculations of this process is quite uncertain, owing to the unavailability of the precise measurement of magnetic field, temperature of electrons and ions and number density at the place of the formation of these structures. However, Morison and Mendis (1978) have shown with the typical values, that these processes can lead to the observable condensation structures.

The time scale of ionization due to such disruption can be estimated as described by Ip (1975). If the ionization took place within a region of \( 10^3 \) km in the inner coma region, the relevant ionization time scale can be expressed as,
Figure 3.28. Wide field photograph of comet Halley taken on 1986 Jan 8. The length of the tail estimated is $\sim 10^7$ km.
Figure 3.29. Schematic drawing of the cometary sub "storm" circuit. (a) Flowing of the cross tail current across the current sheet is steady. (b) Partial interruption of the cross tail current produces a tail aligned current discharging through the cometary ionosphere. It has been suggested that dissipation of the magnetic energy stored in the ion tail in this way may provide the ionization source for the internal ionization mechanism advocated by Wurm (1963).
Where $f_i$ = factor for multiple ionization ~ 10^{-20}

$\sigma_i$ = electron ionization crosssection = \(5 \times 10^{-17}\ \text{cm}^2\)

$I_c$ = fraction of the total current $I_t$, which is discharged for the tail disruption.

Theoretically, Ip and Axford (1982) has shown that for the magnetic field configuration given in Fig. 3.30, the $\mathbf{J} \times \mathbf{B}$ force in the 'o' type loop would tend to focus the cometary plasma in this region, whereas the cometary ion in the vicinity of the x-point would be dispersed. This would lead to the growth of condensation of ionized material in the ion tail.

However, the discussion so far, clearly show the status of a complete understanding of the formation mechanism of such structures. There exist several potential physical mechanisms which can give rise to the observed ionic condensation regions at several parts of the comet, yet the measurements are not adequate to point to a particular physical processes for a given feature. Using the in-situ probes, the chance of obtaining the relevant parameters of these features is low. Hence ground based and well
Figure 3.30. Possible effect of the reconfiguration of the magnetic fields in the ion tail. (a) The quite time structure is shown with the cross tail current without inhomogeneities in the cross tail current sheet. (b) Break up of the current sheet which on one hand would lead to a field aligned current discharging into the ionosphere and on the other, to the formation of X and O type loops would perhaps result in the enhancement of plasma density in the vicinity of the O type loops (Ip et al 1982).
coordinated specialized experiments, mostly with high resolution spectroscopy are of vital importance in this case. The author, therefore, strongly feels the need for such a study in a future active comet.

(C) The acceleration of the condensation:

It is conjectured that the condensation was created nearer to the nucleus as a result of the discharge of cross tail current system followed by the nuclear outburst at 8.1 UT. Assuming that the plasma condensation region has moved in the downstream direction with least lateral diffusion, it is possible to determine the acceleration of the condensation. To determine the mean acceleration 'a' of the plasma in the condensation, we assume that it had an initial velocity $V_0 \approx 1$ km/s at $t_0 \approx 8.1$ UT. The condensation reached at $S = 2.5 \times 10^5$ km after 12.365 hours. In this case the average acceleration needed for the transport of the plasma in the condensation region, from the near nucleus region to the region of observation is,

$$a = \frac{2 (S-V_0(t_1-t_2))}{(t_1-t_2)^2} \approx 25 \text{ cm/s}^2$$

...3.19

where $t_1-t_2 = 12.365$ hours (the time taken for the plasma to move from near nucleus region to the region of
The accelerations of this magnitude are commonly encountered in cometary plasma and several theoretical mechanisms are developed to explain them as discussed in chapter 1. The exact mechanism which might have given rise to the observed acceleration in the present case is not known. However, in what follows, we will outline a simple mechanism accounting for the observed acceleration.

Ip (1980) suggested $\vec{J} \times \vec{B}$ force in the comets due to the field lines towards the anti-sun direction may produce an acceleration of about $\sim 10^{-20}$ cm$^{-2}$. In his model, it is assumed that ion-tail system is two-dimensional with $Z$, pointing in the axial direction and the magnetic field $B$ can be described by having a constant $X$-component,

$$B_x = \text{Cont} \quad \ldots 3.20$$

and a $Z$-component

$$B_z = B_z(\omega)\tanh \left( \frac{x}{L_n} \right) \quad \ldots 3.21$$

where $L_n$ is the width of the current sheet. These equations satisfies the conditions that $B_z \to 0$ as $x \to 0$ and that $B_z \to B_z(\omega)$ as $x \to \infty$ (Tandberg-Hanssen 1924).
If the cometary plasma is further assumed to be isothermal and if there is pressure equilibrium in the $x$-direction, then,

$$\frac{dp}{dx} = -\frac{B^2_z}{4\pi KT} \left[ \frac{dB_z}{dx} - \frac{dB_x}{dz} \right]$$

...3.22

and

$$\int \frac{m_i B_z(\infty)^2}{8\pi KT} = \frac{1 - \tan h^2 \left( \frac{X}{L_n} \right)}{\tan h^2 (\frac{\infty}{L_n})}$$

...3.23

where $K$ is the Boltzmann constant, $T$ the plasma temperature, and $m_i$ the ion mass. Hence the Lorentz force $\vec{J} \times \vec{B}$ can be written as,

$$\vec{J} \times \vec{B} = \frac{1}{4\pi} B_x \frac{d}{dx} (B_z)$$

$$= \frac{B_x B_z (\infty)}{4\pi L_n} \left[ 1 - \tan h^2 \left( \frac{X}{L_n} \right) \right]$$

...3.24

and the acceleration due to the curvature force would be,

$$a = 2 \left( \frac{B_x}{B_z(\infty)} \right) \left( \frac{KT}{m_i} \right) \left( \frac{1}{L_n} \right)$$

...3.25
The Lorentz acceleration is therefore dependent on the ratio of the magnetic field component normal to and parallel to the current sheet, as well as the thermal pressure KT and the width of the cross tail current sheet. In the present case we use the values for $B_x$ from spacecraft measurement data i.e. $B_x \sim 10^4$ and $B_z \sim 10^2$. The same measurements show $L_x \sim 10^6$ and $T \sim 4\times10^2$ K (Galeev A. 1987). Taking these values from eqn (3.25) it follows that

$$a = 24 \text{ cm/s}^2$$

Since this value is close to the observed value, such a mechanism can be responsible for the acceleration of the plasma in the condensation region.

However, once the condensation region reaches the outer coma region, its motion would no longer be governed by the mechanism described above. At this region the solar wind conditions in the victims of comet would mostly control its motion, which is discussed in the following section.

3.3.4 Relation of the observed condensation region with the tail activity

As discussed earlier, several of the ionic features in the tail are thought to be generated within the coma region.
Hence an investigation was carried out to identify the potential tail features (in the wide field photographs taken following our observations) which might be the resultant of the condensation region.

A dramatic disconnection event was observed at a distance of $2 \times 10^6$ km from the nucleus on January 10.375 UT. The front edge of the disconnected tail was seen to move in the north side of the tail in which the condensation was observed. Table 3.11 summarizes the observations of the Comet Halley showing the DE. The observed distance of the front edge of the DE was plotted against the time of the observation. The front between two observations was determined taking a pair of data points at a time. Fig. 3.32 and 3.33 show respectively the position of DE front and its velocity as a function of time. From Fig. 3.33 it is clear that the motion of the DE front was not smooth. Such motions of the plasma feature leading to March 20 and April 11 DE are also deduced (Brosius et al. 1987). These observed variability in velocity and hence in acceleration are due to the manifestation of different forces (e.g. Lorentz force, solar wind dynamic pressure force) dominating the disconnected tail motions at different distances from the nucleus. It is also expected that these individual forces vary with position and/or time. The velocity of the condensation region observed by us is $37 \pm 3$ km/s in the antisolar direction. If it had moved with the same velocity
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Time (UT)</th>
<th>Separation of the DE front ($\times 10^3$ km)</th>
<th>Average velocity (Km/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.375</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10.434</td>
<td>1.9</td>
<td>19.6</td>
</tr>
<tr>
<td>3</td>
<td>10.645</td>
<td>3.0</td>
<td>60.3</td>
</tr>
<tr>
<td>4</td>
<td>10.688</td>
<td>3.4</td>
<td>107.7</td>
</tr>
<tr>
<td>5</td>
<td>10.740</td>
<td>3.5</td>
<td>22.3</td>
</tr>
<tr>
<td>6</td>
<td>10.802</td>
<td>4.0</td>
<td>93.3</td>
</tr>
<tr>
<td>7</td>
<td>11.052</td>
<td>5.3</td>
<td>60.2</td>
</tr>
<tr>
<td>8</td>
<td>11.416</td>
<td>7.6</td>
<td>73.1</td>
</tr>
</tbody>
</table>

These measurements have been taken from various published wide angle comet photograph taken on the time given in column 1.
Figure 3.31. The wide field photographs of comet Halley taken on 10th Jan 1986, showing a dramatic DE.
Figure 3.32. Plot of position of DE front as a function of time on 10th Jan 1986.
Figure 3.33. Plot of velocity of DE front as a function of time on 10th Jan 1986.
in the anti-sun direction, it would have reached a distance of $\sim 5.6 \times 10^6$ km on January 10.375 UT. This is much larger than the distance at which the DE front was observed. However, the preceding discussion show that the motion of such features is not smooth in the anti-solar direction (Fig. 3.33). Therefore if we assume that such a random motion did exist during the period January 8.632 to 10.375 UT, it would have caused an effective deceleration in the anti-solar directions. The observations taken at Yunna Observatory, China following our observations at January 8.93800 has been kindly supplied by Dr. Qin. The wide field photographs taken by them show a Z-shaped thirst at the place about 0.2° away from the nucleus, which moved further to the place 1.3° on January 9.92407. The velocity required for the condensation observed at 8.638 to reach the position of the Z-shaped thirst region at 8.938 UT is $\sim 16$ km/s. In a simple model called "ink model" Jockers (1985) has described such features emerging as a result of the interaction of solar wind with the slow moving tail features such as condensations. Therefore it is reasonable to expect that the condensation observed by us has led to the dramatic DE of 9-10th January 1986. Hence our observation supports the scenario that the dramatic disconnection events in the ionic tail originate deep inside the coma with velocities of $\sim 20-40$ km/s.

3.3.5 Summary and Conclusions:
1) The imaging observations of Comet Halley on 8th January 1980, show a condensation region to the north of the tailward direction of the coma. The analysis shows that the condensation was moving at a velocity of $\sim 37 \pm 4$ km/s in the down stream direction. The investigation on wavelength of the emission shows that the condensation was strong in CO$^+$ ionic emission.

2) From the estimation of the time scale of ionization it is concluded that the ionization of the material in the condensation region was rapid, in a time scale of $\sim 10^3-10^4$ s.

3) Investigation of several processes of ionization mechanism shows that the discharge of crosstail electric currents, passing through the neutral sheet in the near nucleus region is the most probable mechanism for producing the condensation. Hence it is suggested that the condensation was produced at 8.1 UT following a major outburst and accelerated in the down stream direction with an acceleration of $\sim 25$ cm/s$^2$ by the $\mathbf{j} \times \mathbf{B}$ force due to the cometary magnetic field.

4) This feature, most probably is the precursor of the dramatic DE observed on 10th January 1986.

5) These observations therefore support the contention that most of the plasma features observed in the tail have originated in the coma with a initial velocity of $\sim 20-40$ km/s.