4.1 Introduction

Comets have been interesting objects for scientific studies since centuries. In ancient (pre-telescopic era) days only visual studies of comets could be made. With time, technology improved and further studies became practicable. Many comets visit inner solar system periodically and give us occasions to study them. In wavelengths other than radio, particularly in the optical and infra-red bands, much study has been made.

The nucleus of a comet, which has a typical size of
a few kilometers, is composed largely of ices (such as H$_2$O, CO$_2$, etc.) mixed with dust (Whipple, 1950, 1955). When the comet approaches the Sun within ~3 AU, due to sunlight its ices are sublimated carrying with it the molecules and the dust. These form a coma of typical size of about $10^5$ Km. When the comet further approaches the Sun within about 1 AU, the solar ultraviolet radiation dissociates and photoionizes the cometary molecules. These ions interact with the solar wind and move in the anti-solar direction. Indeed, the existence of the solar wind itself was postulated on the basis of observations of cometary ion-tail orientation (Biermann, 1951).

The solar wind moving away from the Sun at a typical speed of about 400 Km/s, carries with it the solar magnetic field. Due to the solar wind pressure, these magnetic field lines drape around the coma of the comet. The ionized particles from the coma follow these curved magnetic field lines and hence the formation of cometary ion-tail takes place (Alfvén, 1957). Due to the polarity reversal of magnetic field lines at sector boundaries with a periodicity of about 7 days, detachment of the old and formation of new ion-tail takes place whenever a sector boundary crosses the tail. This process, called a disconnection event (DE), takes about couple of days to complete.

The comets have induced magnetic field due to comet-solar wind interaction (Alfvén, 1957). A comet has two
types of distinctive tails. The first one is the ion-tail, having plasma phenomena and appears blue due to the emission lines of CO\(^+\). Typical extent of this tail is about \(10^8\) Km, oriented closely in the anti-sunward direction. The other tail is called the dust tail which appears yellowish-red in reflected light. The substructures visible in the ion-tail are in various forms such as rays, streamers, knots, kinks and filaments. Some of these features are caused through interaction with the solar wind (Jockers and Lust (1973); Ip and Axford (1982) and move in the anti-solar direction with velocities about 20-200 Km/s. estimated from successive photographs of the tails.

To make meaningful observations, a comet should be periodic and bright. These criteria were fulfilled by the comet Halley, whose average periodicity is about 76 years.

For its 1985-86 apparition, various ground-based and space-borne observations were planned. During this apparition, the comet Halley was studied (in-situ) by various spacecraft, namely - Vega 1 and 2, Sakigake and Suisei, Giotto and the international cometary explorer (ICE). The missions had three main objectives - (i) to determine the dust content of the comet and distribution of particle sizes. (ii) to determine the nature and quantity of the material that make up the comet's nucleus and (iii) to study processes occurring in the coma and the interaction of the coma with the solar wind. Long awaited recent appari-
tion of the comet Halley was welcomed by the scientists all over the world. For, this was one of the ideal comets for making observations of various features of its coma, dust and ion-tails. The P/Halley shows the full range of cometary activity (jets, halos, dust, ion-tails, etc.) and it also follows a predictable orbit.

Just as the small-scale density irregularities in the solar wind cause scintillations of compact radio sources, known as IPS phenomenon described earlier, it was thought possible that similar density irregularities in a fully developed cometary ion-tail of a strong comet might cause enhancement of scintillations, if the tail occulted a scintillating radio source. Towards this end an attempt was made by Ananthakrishnan et al. (1975), to observe the fluctuations in intensity of the compact source PKS 2025-15, at 327 MHz, when it was occulted by the comet Kohoutek (1973f) on 5 January 1974. They reported that no unique explanation could be given of the intensity fluctuations with 10 sec. periodicity in terms of scintillations produced by cometary plasma. However, Lee (1976) showed that these observations of Ananthakrishnan et al. (1975) could be interpreted as scintillations caused by the turbulent plasma in the comet's tail. In this way the ambiguity persisted for long time, of whether the plasma irregularities present in the cometary tail can cause scintillations or not.

The purpose of our observations of the occultation event in December 1985 was to decide whether the plasma
Fig. 4.1 Relative positions of PKS 2314+03 and Halley's Comet shown on alternate days from 13 through 27 December 1985. Note the occultation of the radio source by the cometary ion-tail during 18 through 20 December.
irregularities in the ion-tail can produce scintillations of a radio source. If yes, what were the densities of the plasma, plasma irregularities, their scale-sizes, etc.

4.2 Observations

Based on International Halley Watch (IHW) predictions, the quasar 3C 459 was to be occulted during 18-20 December 1985. Fig. 4.1 shows the relative positions of the quasar PKS 2314+03 (3C 459) and the Halley's comet as projected on the sky. The IPS telescope at Thaltej (23° 02' 39".48 N, 72° 29' 3".86 E) near Ahmedabad was well-monitored and receiver calibrations were carried out periodically to ensure satisfactory performance of the telescope. Systematic observations of the occultation event were planned. To monitor the background scintillation level, regular observations of IPS of 3C 459, with ~70% of the total flux in the 0.45 arcsec component, were started right from 2 December 1985, when the solar elongation of the quasar was ~103°. In addition, 5 other scintillating and non-scintillating radio sources were observed (viz. 3C 298, 3C 318, 3C 324, 3C 368, 3C 409), which were within 2° to 23° declination range of 3C 459, to have a check on ionospheric and interplanetary transient effects (Hewish et al. 1985).

Fig. 4.2, based on the parameters given in IHW newsletter No.7, shows schematically (not to scale) the geometry of the occultation of 3C 459 by the Comet Halley. Table 4.I,
Fig. 4.2 Sketch of geometry of occultation of PKS 2314+03 by Halley's Comet.
shows some basic parameters regarding this geometry. On 18 December 1985, the angle comet-Earth and source was 4.7° and the comet's position angle was about 66°. The source 3C 459 was 87.5° away from the Sun. Starting from 2 December, only background scintillations (~2 Jy) were observed as the angle source-Earth-Sun was about 90°. On 18 December, an appreciable increase in the scintillations of 3C 459 were recorded when the distance from the comet nucleus to the point of intersection of the line of sight (Earth and source line) with the tail (AC in Fig. 4.2) was 0.12 AU. This increase in scintillations was about 6 times the background scintillations and about 1.5 times the average maximum scintillations recorded for this source at 103 MHz due to solar plasma around 30° elongation.

Fig. 4.2 is a copy of the recordings made during the occultation. Originally, there are three outputs from the correlation type receiver namely, COS, SIN and Scintillometer which are recorded on a strip chart as well as on a digital magnetic tape (Chapter 3). As there were no scintillations on the COS channel, the latter is not shown in this figure. As is evident from this figure, the scintillometer and SIN channels show the maximum scintillations on the 18th. These scintillations progressively reduced from 19th to 21st. In Fig. 4.3, the top trace in each channel shows the SIN output, while the bottom trace shows the scintillometer output. The chart speed on 17 and 18 Decem-
Fig. 4.3 103 MHz recordings during the occultation. Scintillometer and SIN channels show maximum scintillations on 18 December. These scintillations progressively reduced from 19 to 21 December. The top trace in each panel shows SIN output while bottom trace shows scintillometer output. Chart speed on 17 and 18 Dec. was 5 and 10 cm/hr. and 20 cm/hr. thereafter.
ber was 5 and 10 cm/hr respectively, and 20 cm/hr thereafter.

4.3 Data Analysis and Results

The IPS data were recorded on a magnetic tape as well as on a strip chart (as described in chapter 3). From these data the following information was derived:

4.3(a) Scintillation Spectra

Fig.4.4 shows scintillation spectra of the source, computed for 17 through 20 December. It is clear that the area under the curve, which is proportional to the scintillating power, is maximum for the 18 December. Solid lines are least-squared fits to data points. Error bars are standard error. Broadening of the spectra should be noted for 18-20 December. The spectral indices of the simple power-law fits to the high frequency (above 0.6 Hz) data are 2.83 ± 0.20, 2.26 ± 0.15, 2.31 ± 0.14 and 2.40 ± 0.17 or the average power-law index works out to be 2.45 ± 0.25. This corresponds to a wavenumber spectral index of about 3.45, which is close to that expected for a three-dimensional Kolmogorov density spectrum. An average scintillation periodicity estimated from the auto-correlation analysis of the spectra turns out to be about 1 sec.
Fig. 4.4 Scintillation spectra of PKS 2314+03 on 17 through 20 December 1985. Solid lines are least-squared fits to data points. Error bars are standard errors. Note broadened spectra on 18, 19 & 20 December.
4.3(b) Calculation of Scintillation Index

An important parameter, scintillation index ($m$) is defined as

$$m = \frac{\Delta S}{\bar{S}}$$

where $\Delta S$ is the r.m.s. scintillating flux and $\bar{S}$ is the average flux of the source. $\Delta S$ and $\bar{S}$ were calculated using scintillometer output and system calibrations (described in chapter 3). We obtained $\bar{S} = 43$ Jy and the $\Delta S$ values were calculated to be 10.75, 6.45, 3.01 and 2.15 Jy on 18 through 21 December 1985 respectively (Appendix I). The corresponding scintillation indices were 0.25, 0.15, 0.07 and 0.05 respectively.

4.3(c) Calculation of Scale-Size of Irregularity in the Ion-Tail

Assuming the velocity, $v$ of the plasma density irregularities of 100 Km/s (upper limit), (Ershkovich, 1980), the scale-size was calculated to be 100 Kms. by using

$$a = vxt$$

where 'a' is the irregularity scale-size
't'-1 sec., average periodicity of the scintillations.

4.3(d) Calculation of r.m.s. deviation, $\Delta N$; of plasma density

For radio waves from a compact source, incident coherently on a plasma slab (the plasma tail of the comet P/Halley) of thickness 'L', the r.m.s. phase deviation along the line of sight to the source is expressed as (Cohen et al. 1967)

$$\phi_0 = 2^{\frac{3}{4}} \pi^{\frac{1}{2}} r_e \lambda (aL)^{\frac{1}{2}} <\Delta N>$$  \hspace{1cm}(4.c)

where $r_e =$ Classical electron radius,

$\lambda =$ Operating wavelength, and

$<\Delta N>$ = average r.m.s. change in plasma density

Eqn. (4.c) is true for a gaussian electron density correlation function. Under weak scattering condition ($\phi_0 < 1$ radian) Mercier (1962), eqn. (4.c) can be rewritten as

$$m = 2^{\frac{3}{4}} \pi^{\frac{1}{2}} r_e \lambda (aL)^{\frac{1}{2}} <\Delta N>$$  \hspace{1cm}(4.d)

With the help of eqns. 4(a-d), $\Delta N$ can be calculated. The value of 'L', the projected width
of the ion-tail used was $5 \times 10^5$ Km (from the image taken on 10 March 1986 by using the UK Schmidt telescope in Australia). The values of $\Delta N$ calculated were 1.82, 1.08, 0.36 and 0.35/c.c. on 18 through 21 December respectively.

$.\Delta N$ on 18 December = $2 \pm 0.25$/c.c.

4.3(e) Electron Density, $N$ in the Plasma Tail

The estimation of plasma density 'N' in the cometary ion-tail was made assuming proportional to 'N' in the tail. These values of $\Delta N$ and $N$ in the case of solar plasma are known at any heliocentric distance by using (radial distance)$^{-2}$ dependence for both of them. Now, at a particular distance from the Sun, $\Delta N$ in the cometary tail was obtained from the present observations, while the same for the solar wind outside the tail was estimated using (distance)$^{-2}$ dependence. Also, the values of $(N)_{solar}$ are known for that distance. Hence, by comparison $(N)_{cometary}$ was calculated for that distance. This procedure is elaborated below for 18 December 1985.

On 18 December the $\Delta N$ value in the plasma tail was calculated from observations at anti-sunward radial distance, 1.34 AU from the sun which is
about 2/c.c. Now, \( \Delta N \) and \( N \) in the case of solar plasma (calculated) at 1.34 AU (outside the tail), (Rees et al. Private communication) are .06 and 6/c.c. At this distance the ratio

\[
\frac{(\Delta N)_{\text{comet}}}{(\Delta N)_{\text{solar}}} = \frac{1.82}{.06} = 30.34 \quad \ldots (4.e)
\]

the same ratio of \( N_{\text{comet}} \) and \( N_{\text{solar}} \) is assumed to hold good at 1.34 AU from the sun.

\[
\text{i.e.} \quad \frac{(N)_{\text{comet}}}{(N)_{\text{solar}}} = 30.34 \quad \ldots (4.f)
\]

or

\[
N_{\text{comet}} = 182/c.c. \quad \ldots (4.g)
\]

\[
\therefore N_{\text{comet}} = 200 \pm 25/c.c. \text{ at } 0.12 \text{AU from cometary nucleus.}
\]

In-situ measurements made by the American spacecraft ICE, in March 1986 gave the range of \( N \) in the ion-tail of comet Halley, 20 - 600/c.c. The value of \( N \) estimated from the present IPS observations falls within this range.
4.3(f) The value of $\Delta N$ in the ion-tail; calculated from the Kolmogorov spectrum

The value of $\Delta N = 1.82$/c.c. on 18 December 1985, was calculated assuming a gaussian irregularity spectrum. However, a Kolmogorov spectrum for turbulent media such as the solar wind, Earth's atmosphere and the stellar wind is more realistic. An attempt has been made to estimate the value of $\Delta N$ by assuming a Kolmogorov turbulent plasma in the ion-tail of comet Halley. Lee and Jokipii, (1975a) have shown that the correlation function of phase also has a Kolmogorov spectrum

$$P_{\phi}(q) = A(1+q^2 L^2)^{-\alpha/2} \exp(-q^2 l^2/2) \text{ for } L \gg 1$$

...(4.h)

where $L = \text{Coherence or outer scale}$

$\ell = \text{inner scale}$

$q = \text{wavenumber}$

This spectrum is

flat for $q < L^{-1}$

power-law with index $-\alpha$ for $L^{-1} < q < \ell^{-1}$

and cut off for $q > \ell^{-1}$.

Usually $-4 < \alpha < -3$ and particularly $\alpha = -11/3$ for
Kolmogorov spectrum. A, a constant is defined as

\[(a/2 - 1) L^2/\pi; \text{ for } L>>1 \quad \text{(4.i)}\]

Lee (1976), has shown that the correlation scale of intensity is

\[l_c = 1, \text{ for } l > (Z/K)^{1/2} \]

\[= (Z/K)^{1/2} \text{ for } l < (Z/K)^{1/2}\]

where \(Z\) is the distance to the observer and \(K = 2\pi/\lambda\).

\(l_c = v.t_1 = 100 \text{ Km; since } v=100 \text{ Km/s (assumed)}\) and \(t_1\) (periodicity of intensity variation) estimated to be about 1 sec. So, in the present case, \(l_c \neq (Z/K)^{1/2}\), therefore we assume \(l_c = 1\), inner scale of turbulence in the plasma tail of the comet, which is about \(10^2\) Km. Assuming the outer coherence scale, \(L\), to be comparable to the width of the cometary tail, \(L \sim 5 \times 10^5\) Km and taking the value of the scintillation index on 18 December 1985, which is about 0.25, we get \(\Delta N = 1.4/\text{c.c.}\) for a Kolmogorov turbulence. This estimation is worked out as follows.
\[ \phi_0^2 = \frac{M_z^2}{A(\frac{Z}{K})^2 \cdot 8\pi \cdot \frac{7}{6} \cdot L^{-7/3} \cdot L^{-11/3}} \] \tag{4.j}

where \( M_z \) is scintillation index.

This equation gives the value of \( \phi_0^2 \) to be about \( \approx 3.6 \times 10^3 \) radian\(^2\).

Now, writing \( \Delta N^2 \) as (Lee and Jokipii, 1975b)

\[ (\Delta N)^2 = \frac{\phi_0^2}{76.8 \pi^{7/2} \cdot L \cdot r_e^2 \cdot e^{-2} \cdot D \cdot \frac{71/6}{71/3}} \] \tag{4.k}

and taking \( L = D \), this equation gives the value of \( \Delta N \) to be about 1.4/c.c. for a Kolmogorov turbulence in the ion-tail.

It is very interesting to note that this value of \( \Delta N \), 1.4/c.c., is very close to the value of 1.82/c.c. calculated assuming gaussian turbulence in the cometary ion-tail. Also, the average wavenumber spectral index turns out to be very close to the Kolmogorov value (-11/3).

These parameters along with other calculated/estimated parameters are shown in Table 4-II.
4.4 Discussion

The present IPS observations were made when the solar elongation of the source 3C 459 was \( \sim 90^\circ \). At such solar elongations, the scintillation recorded, if any, are weak, as the telescope points far away from the Sun where the solar plasma and irregularities are sparse. Any possibility of interference causing such scintillations is ruled out because the scintillations recorded were maximum on 18 December and then progressively decreased on 19 and 20 December. No correlation was observed between the enhancement and ionospheric phenomena such as sporadic E and spread-F. Solar activity during the period of these IPS observations was 'very low', while geomagnetic activity was 'quiet to unsettled' with no Sc-type magnetic storms as reported by (Pre. Report and Forecast of Solar Geophysical Data Joint NOAA-USAF Space Environment Service Center, 1985). During this period, IPS observations of five other scintillating and non-scintillating sources were made, some of which were within 8° declination of the occulted source. None of these sources, except the quasar PKS2314+03 (3C 459) showed any enhancement of scintillations. Hewish et al. (1985) showed that interplanetary transients cover a solid angle of \( \sim \pi/2 \) Sr. Also, according to them, there is a strong correlation between enhancement in scintillation and mean plasma density along the line of
sight to a source. As the enhancements in scintillations were recorded only in the case of 3C 459, the density increase was restricted in that direction only. We, therefore, concluded that the observed enhanced scintillations of 3C 459 were caused by the ion-tail of the comet Halley.

There are a few other observations of occultation of radio sources by cometary ion-tails. These will now be discussed and compared with our IPS observations at 103 MHz made during the pre-perihelion period.

Ananthakrishnan et al. (1975), reported fluctuations in the intensity of the extragalactic source PKS 2025-15 observed during its occultation by the coma and tail of the comet Kohoutek (1973f) on 5 January 1974. These observations were made at 327 MHz using the Ooty radio telescope. At the time of these observations the solar elongation of the source was 20°. These authors concluded that no radio emission above the confusion limit of the Ooty radio telescope could be detected from the comet Kohoutek (1973f). But fluctuations in the intensity of the occulted source were observed. (Although the authors did not uniquely attribute these fluctuations to the plasma in the ion-tail). However, Lee (1976) interpreted these scintillations as caused by the turbulent plasma in the ion-tail of the comet even though their periodicity was about 10 sec.

Slee et al. (1987) reported enhancement of scint-
tillations when the compact radio source 1827-360 was occulted by the Halley's comet on 29 March 1986 (Post-perihelion period). This was as much as 4 times the background scintillation level. These observations were made using Parkes 64-m telescope at 408 MHz. During these observations, the solar elongation of the occulted source was 89° and the geocentric velocity of the comet Halley was \(-40\) Kms\(^{-1}\). The topocentric and heliocentric distances of this comet were 0.576 and 1.143 AU respectively and the projected distance from the nucleus, at which the tail passed in front of the source, was 5.4 \times 10^6\) Km. These authors have deduced \(\Delta N\) in the ion-tail to be 1.8/c.c. for a gaussian electron density correlation function. The same for a Kolmogorov power-law spectrum, with an inner scale of 100 Km and an outer scale of 4.8 \times 10^5\) Km, was estimated to be 1.4/c.c., which is very close to the value for a gaussian spectrum. These results agree well with the results described earlier.

Hajivassiliou and Duffett-Smith (1987), used the data recorded at Cambridge during the IPS survey at 81.5 MHz to make a retrospective search for enhanced scintillation caused by cometary tails. The data covered the period May 1978-March 1981 and comprised daily measurements of the r.m.s. scintillating flux density on about 2000 radio sources at all values of right ascension north of declination -10°. From these data base, these authors
found a sample of 35 comets out of which, 12 comets were identified as sufficiently bright to promise an effect and whose tails occulted about 45 bright scintillating sources observed in the survey. They concluded that there was no convincing evidence for enhanced scintillations of radio sources due to plasma density irregularities in the ion tails of the comets.

The observations of Hajivassiliou and Duffett-Smith were not really planned for occultation events by cometary ion-tails. The visual magnitudes of 8 out of 12 comets were in excess of 10 and had no reports on tail lengths of 6 comets; the remaining 5 comets had tail lengths of less than 2° and only one comet had a tail length of 5°. Their telescope could observe each source only for 2 minutes. Therefore, there were 58% chances of missing an occultation. In addition, comets slow proper motion which implied large uncertainties in the calculated moments of the occultations which confused their data. These authors therefore concluded that their observations did not entirely rule out the possibility of scintillations caused by cometary tails, since the comets used by them were faint and many of them carried no report of a tail being observed.

Ananthakrishnan et al. (1987) attempted to observe scintillations of four radio sources occulted by the ion-tail of the comet Halley at 327 MHz, using the Ooty radio
telescope. These sources were: 2052-106 ($\Delta S \approx 0.5$ Jy), 2021-168 ($\Delta S = 0.3$ Jy), 1921-293 ($\Delta S \approx 5$ Jy) and 1817-391 ($\Delta S \approx 1.2$ Jy). The last source was confused with 1815-391. Each occulted source, together with the corresponding nearby control sources, was observed for 15-20 min. alternated between 10 min. of observations of each of the control sources. Each observation was made for three days, the middle one being the day of occultation spread over 6-9 hr.

A description of only three occulted sources is given by these authors. The source 2052-106 was observed during 10-12 February; source 1817-391 was observed on 1 and 3 April and the source 1921-293 was observed during 23-25 March 1986. Based on these observations, the authors concluded that no significant increase in the level of turbulence was observed that could be attributed to the plasma tail.

These observations were not made in favourable conditions which are governed mainly by proper solar elongation of the source and the conditions of the cometary plasma tail. The solar elongation of the source 2052-106 during the observations was approximately 10°. Fig. 4.5 shows the geometry of the occultations of PKS 2314+03 and 2052-106 by Halley's plasma tail during 18-20 December 1985 and 11 February 1986. At 327 MHz the maximum scintillation of a scintillating source due to solar plasma occurs around
Fig. 4.5 Geometry of occultations of PKS 2314+03 and 2052-106 by ion-tail of Comet Halley during 18-20 December 1985 and on 11 February 1986.
14° solar elongation. Consequently, bulk of the scattering took place in a relatively thin layer of the solar plasma centered around the point of closest approach to the source 2052-106. Corresponding control sources were also within 12° of the Sun. Therefore, the enhancement due to the cometary tail was not detected. The source also got broadened due to the strong scattering, resulting in reduction of the scintillations. Furthermore, due to the nearly 18° inclination angle between the ecliptic and the orbital plane of the Halley's comet, this line of sight might intersect the cometary tail at a point much towards its far end; and it will not intersect at all if the two planes were coincident. But this effect is only 5%. Thus, the event reported by Ananthakrishnan et al. was unsuitable to observe any enhancement of scintillations that would have been caused by a strong comet like Halley. The third occulted source was 2021-168 when the observations were made on 2 March 1986. Due to poor signal-to-noise ratio no observations are reported in their paper. This is very likely due to a disconnection event (DE) on 1 March UT which might have made the occultation ineffective. In the case of DE's, the entire plasma tail uproots itself from the head of the comet in the anti-sunward direction and after about a couple of days, it is replaced by new plasma tail. If such observations are made during DE's, scintillation may not be caused. The observation of the
third occulted source, 1921-293 is shown to be made on 24 March 1986. An enhancement of \( \sim 10\% \) was shown by this source when it was within 10 arcmin. of the ion-tail. The last occulted source in their investigation was 1817-391 with its control source 1827-360. This observation was made on 1 and 3 April. From their Fig. 3(a), it can be estimated that the enhancement in the case of the occulted source was about 60\%, while that for the control source (1827-360) was about 20\%. Even then they described these two enhancements as similar. The DE's were reported by IHW participants and prepared by Dr. Niedner, Jr. NASA/GSFC (Private Communication).

Important information, regarding these observations, is summarised in Table 4-III.

4.5 Conclusions

As has been described earlier, a few attempts were made to record enhanced scintillations of compact radio sources attributable to density irregularities in the occulting cometary plasma tails. In addition, Hajivassiliou and Duffett-Smith (1987) analysed an extensive data base of IPS of about 2,000 sources recorded during 1978-81. They came across many events of occultations of scintillating sources by several comets. Most of these comets were faint and there was no information on their cometary tails. Also, due to their very short time (2 minutes) of observations on each source, nearly 58\% of the occultation events
were missed. Due to these uncertainties of observations they concluded that they could not entirely rule out the possibility of cometary plasma tails giving rise to enhanced scintillations of radio sources.

The recent observations of Ananthakrishnan et al. (1987) studied in reality three events of occultations of radio sources by the Halley's plasma tail. We have indicated that one of the events reported by these authors failed to observe enhanced scintillations attributable to the cometary tail due to very unfavourable geometry during that event. During another event the Halley's tail was very likely affected by a DE. In the case of the events during 1-3 April 1986, their observations do indicate enhanced scintillations. On 1 April, there was substantial enhancement in the scintillations and on 24 March, this enhancement was ~10%. In both these cases the ion-tail was within 10 arcmin. of the line of sight. These were misinterpreted in terms of reasons other than the cometary plasma tail.

The important requirements of favourable geometry of occultation, monitoring of background level of scintillations during and after an occultation event, covering of a sufficiently large region around the occulted source to monitor effects of interplanetary transients, geomagnetic storms and ionospheric phenomena and complete information on the cometary plasma tail were satisfied during our
observations at 103 MHz in December 1985. We, therefore, concluded that the enhanced scintillations observed by us were caused by the Halley's plasma tail.

In view of the importance of studying the plasma tail by radio occultation method, it would be beneficial to make coordinated observations at various wavelengths as described in chapter 7.
## TABLE 4-I

**Parameters of Halley's comet**

<table>
<thead>
<tr>
<th>Date Dec. 1985</th>
<th>Solar elongation (Comet-Earth-Sun angle) in degree</th>
<th>Δ(Geocentric distance of comet) in AU</th>
<th>R (Heliocentric distance of comet) in AU</th>
<th>Δ(Geocentric velocity of comet) Km/sec</th>
<th>¨R (Heliocentric velocity of comet) Km/sec</th>
<th>Halley comet's declination (1950)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>84.1</td>
<td>0.86</td>
<td>1.24</td>
<td>33.47</td>
<td>-26.74</td>
<td>+2° 36'.02</td>
</tr>
<tr>
<td>18</td>
<td>81.8</td>
<td>0.88</td>
<td>1.22</td>
<td>33.92</td>
<td>-26.76</td>
<td>+2° 7'.67</td>
</tr>
<tr>
<td>19</td>
<td>79.6</td>
<td>0.90</td>
<td>1.21</td>
<td>34.29</td>
<td>-26.78</td>
<td>+1° 40'.73</td>
</tr>
<tr>
<td>20</td>
<td>77.5</td>
<td>0.92</td>
<td>1.19</td>
<td>34.58</td>
<td>-26.79</td>
<td>+1° 15'.13</td>
</tr>
<tr>
<td>21</td>
<td>75.4</td>
<td>0.94</td>
<td>1.18</td>
<td>34.80</td>
<td>-26.80</td>
<td>+0° 50'.80</td>
</tr>
</tbody>
</table>

* IHW newsletter no.7.
TABLE 4-II

Calculated parameters from the occultation observations

<table>
<thead>
<tr>
<th>Date (Dec. 1985)</th>
<th>Scintillating flux, ΔS (Jy)</th>
<th>Scintillation index, m</th>
<th>r.m.s. change in density(ΔN) el/c.c.</th>
<th>Tailward distance from the nucleus to the line of sight in AU</th>
<th>Estimated density N el/c.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>2.15*</td>
<td>0.05*</td>
<td>0.36*</td>
<td>0.080</td>
<td>36*</td>
</tr>
<tr>
<td>18</td>
<td>10.75</td>
<td>0.25</td>
<td>1.82</td>
<td>0.121</td>
<td>182</td>
</tr>
<tr>
<td>19</td>
<td>6.45</td>
<td>0.15</td>
<td>1.08</td>
<td>0.144</td>
<td>108</td>
</tr>
<tr>
<td>20</td>
<td>3.01</td>
<td>0.07</td>
<td>0.36</td>
<td>0.178</td>
<td>36</td>
</tr>
<tr>
<td>21</td>
<td>2.15*</td>
<td>0.05*</td>
<td>0.36*</td>
<td>0.204</td>
<td>36*</td>
</tr>
</tbody>
</table>

* Values equivalent to the control, (average) days.
<table>
<thead>
<tr>
<th>Place &amp; Frequency of Operation</th>
<th>Observation Period</th>
<th>Scintillating Sources occulted</th>
<th>$S$ Jy &amp; Solar elong.</th>
<th>Comet used</th>
<th>Information on Cometary Tail</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahmedabad (India) 103 MHz</td>
<td>18-20 Dec. 1985</td>
<td>PKS 2314+03 (3C 459)</td>
<td>11 Jy 85°</td>
<td>Halley</td>
<td>Length</td>
<td>3 days' observations by factor of 6 over background scint.</td>
</tr>
<tr>
<td>Parkes (Australia) 408 MHz</td>
<td>29 Mar.86</td>
<td>1827-360</td>
<td>10.6 Jy 89°</td>
<td>Halley</td>
<td>10°</td>
<td>Enhancement of 4 times</td>
</tr>
<tr>
<td>Ooty (India) 327 MHz</td>
<td>11 Feb.86</td>
<td>2052-106</td>
<td>0.5 Jy 10°</td>
<td>Halley</td>
<td>Nil</td>
<td>Solar wind contribution to scint. dominating</td>
</tr>
<tr>
<td></td>
<td>2 Mar.86</td>
<td>2021-168</td>
<td>0.3 Jy 37°</td>
<td>&quot;</td>
<td>DE on Mar.1 UT</td>
<td>S/N poor; no observations</td>
</tr>
<tr>
<td></td>
<td>24 Mar.86</td>
<td>1921-293</td>
<td>5 Jy 74°</td>
<td>&quot;</td>
<td>Nil</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1 Apr.86</td>
<td>1817-391</td>
<td>1.2 Jy 96°</td>
<td>&quot;</td>
<td>Confused with 1815-391</td>
<td>58% chance of missing the occultation.</td>
</tr>
<tr>
<td>Cambridge (UK) 81.5 MHz</td>
<td>May 1978 - March 1981</td>
<td>35 90°-100°</td>
<td>12 Comets</td>
<td>None for 6 comets; one comet 5°, rest less than 2°</td>
<td>No information on DE.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX I

Calculation of scintillating flux (ΔS) and scintillation index (m) of 3C 459 during its occultation by the ion-tail of Comet Halley:

Scintillation index is defined as

\[ m = \frac{\text{Scintillating flux, } \Delta S}{\text{Mean flux, } \bar{S}} \]

The mean flux of the source was calculated by using the system calibration, Fig. 3.6 and eqn. (3.a). This value was estimated to be about 43 Jy.

The scintillating flux, ΔS was estimated using eqn. (3.f) which is

\[ \Delta S = 2 \sqrt{\Delta I} \text{ Jy} \]

where ΔI is the scintillometer deflection.

The value of ΔI, read from the strip chart (Fig. 4.3) of 18 December 1985, was about 27 and hence

\[ \Delta S \approx 2 \sqrt{27} \approx 10.4 \text{ Jy} \]

\[ m = \frac{\Delta S}{\bar{S}} = \frac{10.4}{43} = .242 \]

This value of m, was used in further calculations of ΔN. Similar calculations were also made for the other dates of occultation.