Chapter 3

Wing Intensity in Fabry-Pérot fringes

One of the outstanding differences that is markedly seen, when the 1980 and 1983 eclipse interferograms are compared, is that fringes in the 1980 eclipse interferograms show much lower contrast. The observed contrast showed large variations in radial and azimuthal directions. In this chapter the probable mechanism which cause the reduction of contrast are discussed. The reduction of contrast essentially implies the presence of rather large intensity in the wing region of the FP line profiles. Appropriate corrections were performed for various contrast reducing factors which are inherent in the FP etalon system. In addition to this, the presence of continuum radiation in nearby wavelengths may contribute to the wing intensity. This factor is computed in detail for the given FP, for the actual values of line and continuum intensities in the corona, which were independently measured. Here, the line intensity refers to the integrated intensity across the line while the continuum intensity refers
to the white light intensity measured per angström. Calculations were performed to remove the continuum intensity which may be present at the wings. Wing intensity refers to the additional intensity which is still present in the fringe minima position after the above corrections. It is found that the wing intensities show a marked correlation with the coronal position angles. The results and a probable interpretation are given in the final sections.

### 3.1 Factors which affect the Wing Intensity

There can be five factors which may broaden an FP fringe and consequently raise the wing intensity. They are

- Instrumental broadening
- Broadening due to the finite width and intensity of the observed profile
- Presence of continuum radiation in the nearby wavelengths
- Presence of large scale turbulence in the medium
- Presence of fast moving discrete components along the line of sight

In the following section the various instrumental broadening factors are briefly explained, and the appropriate contributions as applied to the observed profiles are mentioned.

The various instrumental broadening factors are explained in chapter II. Close-ly following the lines of Chabbal (1953), we calculate the expected contrast in a given
fringe taking an instrumental function of width 0.28 Å as obtained from the calibration fringes and a source function having a width approximately equal to the observed Doppler width. The expected contrast is then compared with the observed contrast in the line profile and the difference is taken as the wing intensity.

The observed contrast in the FP fringe is calculated as follows. Relative intensity values at the fringe minima positions i.e. at the two edges of the fringe profile are read out from the PDS data. A straight line is fitted to them and the fitted value at the center is taken as the average fringe minimum intensity. Observed contrast is then obtained by dividing the fringe peak intensity by the fringe minimum intensity. Relative intensities at the FP wings are small compared to the fringe peak intensities, and hence the error in their measurement is rather high, being about 10%.

The contrast in an ideal etalon is approximately \( \frac{4N_R^2}{\pi^2} \). However in practice there may be many contrast reducing factors. They may be conveniently treated in terms of transmission factors associated with the etalon. The expected contrast for a fringe may be written as (Chabball 1953)

\[
C_{\text{exp}} = \frac{\tau}{\tau_A} \frac{4N_R^2}{\pi^2} \tag{3.1}
\]

where \( N_R \) is the reflective finesse, \( N_R = 22.5 \), for the given FP with reflectivity \( R = 0.87 \). \( \tau \) is the actual transmission in the FP, which is given by

\[
\tau = \tau_A \times \tau_B \times \tau_E \times \tau_F \tag{3.2}
\]

Where,

\( \tau_A \) is the transmission factor due to the absorption losses in the reflective layers of the etalon. For the dielectric reflective coatings, absorption is negligible and hence \( \tau_A \) is approximately one.

\( \tau_B \) is the transmission factor due to the source not being monochromatic and is given
by Chabbal (1953). Presence of microturbulence in the corona may also contribute to the line broadening, the distribution of which is taken as a Gaussian, and was treated together with the thermal broadening.

$\tau_E$ arises due to etalon defects. Plots of $\tau_E$ as a function of Airy width are given by Chabbal (1953).

$\tau_F$ arises due to the scanning function. For the typical grain size of 10$\mu$m, the solid angle subtended by the grain at the imaging lens is very small and correspondingly the broadening due to the scanning function is negligible. Hence $\tau_F$ is approximately one.

For the given FP interferometer, $\text{fsr}=4.65$ Å, and for the coronal green emission line of width 0.75 Å which accounts for a two million degree corona, and an assumed microturbulent velocity of 7 km s$^{-1}$, we find $\tau_A=1$, $\tau_B=0.40$, $\tau_E=0.90$, $\tau_F=1$, the expected contrast is about 60. For the observed width of coronal line profiles 0.60–1.0 Å, the expected contrast is in the range 70–54.

The actual wing intensity may be written as

$$I_w = I_m \left( \frac{1}{C_{\text{obs}}} - \frac{1}{C_{\text{exp}}} \right)$$  \hspace{1cm} (3.3)

where $C_{\text{obs}}$ is the observed contrast in the fringe, $I_m$ is the fringe peak intensity. A computer program was written to do the above calculations sequentially. Various steps involved in the calculation may be summarized as following.

- Determination of the width of the line profile
- Interpolation to find $\tau_B$ from Chabbal (1953)'s curves
- Calculation of $\tau$ using $\tau_E$ from instrumental profile and $\tau_A$ and $\tau_F$
• Determination of the observed contrast

• Calculation of the wing intensity

3.1.1 Effect of Continuum Radiation in nearby Wavelengths

If the continuum radiation in nearby wavelengths is appreciable in comparison with the line intensity, the observed wing intensity may be affected by the continuum radiation. For an ideal etalon and Lorenzian line profile, Hernandez (1966) gives the fraction of the continuum transmitted as

\[ f = \frac{1}{2\pi A(0)} = \frac{1 - R}{1 + R} \]  

(3.4)

where \( A(0) \) is the minimum intensity of the Airy profile. However, with a line profile which is substantially broadened thermally, and for an actual etalon whose instrument function is broader than the Airy profile, the continuum contribution may be different. To see this effect, a simple coronal line profile with a finite contribution from the continuum radiation, as recorded by the instrument was modelled. A Gaussian line profile with halfwidth 0.75 Å with possible values of the continuum was assumed as the source function. Line to continuum intensity ratio was found to be in the range 100-1 in the coronal heights 1.10-1.30 R\(_\odot\) (see chapter v).

The recorded line profile should be obtained by the Fourier convolution of the source function with the instrumental function. The instrumental profile is obtained by scanning the calibration interferogram, which was obtained with a laboratory source, mercury green line at 5461 Å. An Airy function with halfwidth 0.23 Å convolved with a Gaussian function of equal halfwidth, which account for the additional
broadening factors, was found to describe the instrumental profile reasonably well. The instrumental profile and the convolved function are shown in Figure 3.1.

In the next stage, we have taken a Gaussian source function with a certain value of the line to continuum intensity ratio and computed its transmission through the interference filter. The transmitted intensity was then convolved with the instrumental function by Fourier transform methods. A computer program was written and used for this purpose. The Fourier convolution of the source function $S(\lambda)$ and the instrument function $I(\lambda)$ may be given as

$$O(\lambda_k) = S * I(\lambda_k) = \int_{-\infty}^{+\infty} S(\lambda_k - \lambda_i) I(\lambda_i) d\lambda$$

The above formula may be given in the discrete form as (Press et al., 1988)

$$O(\lambda_k) = S * I(\lambda_k) = \sum_{\lambda_i = \lambda_1}^{\lambda_2} S(\lambda_k - \lambda_i) I(\lambda_i)$$  \hspace{1cm} (3.5)

where $(\lambda_2 - \lambda_1)$ is the filter pass band.

The line to continuum intensity ratio is varied through its possible values and the calculations were performed. In Figure 3.2a, we have plotted, the source function with a typical line to continuum intensity ratio of 10, filter transmission profile and the transmitted source function. The instrument function and the convolved line profile are shown in Figure 3.2b and table 3.1 gives the details of calculation. It may be seen that, unless the ratio of line to continuum intensity is less than 10, continuum contribution has no effect on the fringe contrast. It is evident from the table that as $I_c \rightarrow 0$, ie when $I_l/I_c$ is large, the expected contrast $C_{exp}$ almost become equal to the value obtained from Chabbal (1953).
Table 3.1: Contribution of the continuum intensity to the fringe contrast: The first column of the table gives the value of the ratio of line to continuum intensity, the second and third give the computed fringe maxima intensity and fringe minima intensity for a normalized source function. The next two columns give the percentage of the ratio of wing intensity to peak intensity and the contrast arising due to continuum contribution.

<table>
<thead>
<tr>
<th>$I_l/I_c$</th>
<th>$I_m$</th>
<th>$I_w$</th>
<th>$I_w/I_m$ %</th>
<th>$C_{exp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.794</td>
<td>0.0727</td>
<td>9.15</td>
<td>10.93</td>
</tr>
<tr>
<td>2.5</td>
<td>0.782</td>
<td>0.0358</td>
<td>4.57</td>
<td>21.87</td>
</tr>
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<td>5</td>
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<td>0.022</td>
<td>2.83</td>
<td>35.36</td>
</tr>
<tr>
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<td>0.776</td>
<td>0.0183</td>
<td>2.35</td>
<td>42.52</td>
</tr>
<tr>
<td>10</td>
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<td>0.0154</td>
<td>1.98</td>
<td>50.46</td>
</tr>
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<td>0.0129</td>
<td>1.66</td>
<td>60.11</td>
</tr>
<tr>
<td>20</td>
<td>0.774</td>
<td>0.0123</td>
<td>1.59</td>
<td>62.67</td>
</tr>
<tr>
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<td>1.25</td>
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<td>0.773</td>
<td>0.0091</td>
<td>1.18</td>
<td>84.71</td>
</tr>
</tbody>
</table>
Fig. 3.1 Instrumental profile; relative intensity in arbitrary units against wavelength difference from the maximum.
Fig. 3.2 Details of the convolution program: relative intensity in arbitrary units is plotted against wavelength for the mentioned curves.
3.2 Presence of Discrete Components in the Corona

Typical intensity profiles derived from the 1980 and 1983 observations are shown in Figure 3.3. It may be noted that wing intensities are large in the 1980 fringe profiles while they are very low in the 1983 profiles. About 500 line profiles derived from FP interferograms belonging to the 1980 corona were examined to see the wing intensities. Many of the line profiles showed an elevated wing intensity. From the above section, it is clear that the observed reduction of contrast cannot be explained by the contribution of continuum intensity to the wings. Wing intensities must be then dominated by large scale turbulence or by Doppler shifted green line components which arise due to the discrete moving components in the line of sight. Large scale turbulence with a most probable velocity of $\sim 150 \text{ km s}^{-1}$, if present in the corona, may explain such an effect. However, the presence of such large scale turbulence have not been reported in the corona. Moreover, line profiles often show a distinct asymmetry which is not normally expected for the distribution of turbulent eddy velocities. The expected distribution of large scale turbulent velocities is a Gaussian, and hence may contribute to the emission line broadening. However, an asymmetry of the line profile may not result from such a case. On the other hand, large scale flow observed in coronal loops seems to be a good candidate in explaining the wing intensity. Also, it is to be noted that many of the line profiles show signatures of moving components (see chapter 4). The presence of discrete components such as coronal loops are seen in large number in the coronal pictures (Vaiana & Rosner 1978, Priest 1984). Coronal loop flows are reported by many authors (Athay et al., 1983b, Kopp et al., 1985).
Fig. 3.3 Typical intensity profiles in the 1980 & 1983 interferograms; relative intensity in arbitrary units plotted against radial distance from the fringe centre in the interferogram. Line profiles in the 1980 interferogram show excess intensity at the wing region, as compared to that of 1983 interferogram.
It was found that wing intensities have a pronounced correlation with the coronal position angles. This is illustrated in Figure 3.4a–l, where we have plotted the fringe peak intensities against coronal radial distance in the upper half, and the wing intensities against coronal radial distance in the lower half. Observed values in a 2.5° interval on either side of the particular position angle are included in every plot. This explains the large scatter in the diagram. A least square third degree polynomial fit is also given along with, to see the trend. The position angles 350, 10 and 20 represent polar coronal hole region. The existence of wing intensity at these position angles indicates the presence of discrete components in the coronal hole region. It may be seen that at these position angles, the wing intensities roughly follow the fringe peak intensities. The variation of fringe peak intensities in coronal heights can be taken as the variation of green line intensity. The line intensity reflects the excitation conditions under which the particular emission line originates. In other words, it is a representative of the physical conditions existing in the medium such as electron density, temperature and chemical abundance. Since we are dealing with the same ion, chemical abundance need not be taken into account. The coronal green line intensity is found to be a strong function of temperature and electron density (Jordan 1969, Raju & Singh 1987, Raju et al., 1991). Thus, the covariation of wing intensity and line intensity implies similar excitation conditions existing in the regions from which they arise. Since the wings represent discrete components and the line peaks represent the ambient medium (see chapter 4), this indicates the similar physical conditions prevailing in them. A large number of coronal loops dissipating into the ambient medium may explain such an effect.

In the remaining position angles, however, line intensity and wing intensity do not show covariation. This must, then imply the dissimilar physical conditions prevailing in the discrete components and in the ambient medium. In the case where
Fig. 3.4 Relative intensity in arbitrary units is plotted against coronal radial distance in units of $R_{\odot}$; the upper half of each graph represents the fringe peak intensity and the lower half represents excess intensity in the wings; respective position angles are mentioned.
Fig. 3.4 continued
Fig. 3.4 continued
the kinetic temperature in the ambient medium and in the coronal loops are different, the line intensity and the wing intensity may show dissimilar intensity variations along the coronal heights. It is well known that the presence of strong magnetic fields in the coronal active regions have a ‘blanketing effect’ on the flux tubes i.e. it allow the existence of thermally isolated coronal loops (Priest 1984). It is interesting to note that the covariation of wing intensity and line intensity breaks down in the strong field regions such as in streamers and active regions where the possibility of finding thermally isolated loop structures exists.

It may also be seen from Figure 3.4 that the variation of wing intensities is strikingly different in different position angles while line intensities show more correlation amongst them. One possible inference is that the similar variation of the physical conditions with coronal heights existing in the ambient medium. In coronal loops, the observation imply that the variation of kinetic temperature and electron density is quiet different throughout the corona.

No appreciable wing intensities are seen in the 1983 interferogram fringes. Line intensity itself is very weak in 1983 corona and the emission recorded was restricted to only a few pockets. Even in regions where fairly strong emission was recorded, the contrast remained high. It is inferred that fast moving discrete components are either absent or weak in the 1983 corona in comparison with the 1980 corona. The above discussion, though only qualitative in nature, emphasizes two points, namely the ubiquitous nature of coronal loops and the importance of magnetic field in solar corona.