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Evidence for Moving Features in the Corona from Emission Line Profiles Observed during Eclipses

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Abstract. Using the line profiles of [Fe x] 6374 Å and [Fe XIV] 5303 Å emission lines observed during five total solar eclipses, we address the problem whether the solar corona is static or contains moving features. Many of the profiles of both emission lines have complicated shapes, which we interpret as an evidence for the existence of many, small, moving features in the corona. The line-of-sight velocities observed by other investigators (*e.g.* Desai, Chandrasekhar & Angreji 1982) also support this view. On the other hand, about 15 recent interferometric and multislit investigations of coronal emission lines have not shown evidence of moving elements. We suggest that this is due to insufficient spatial resolution.

Key words: solar corona, emission line profiles—solar corona, moving features

1. Introduction

It is generally believed that the inner solar corona is static, with no macroscopic movements larger than a few km s^{-1}. On the other hand, considerable velocities are exhibited by the chromosphere and solar wind. It is difficult to understand how the static corona exists between these two. In order to resolve this apparent contradiction, we have begun observations of coronal lines [Fe x] 6374 Å and [Fe XIV] 5303 Å simultaneously during solar eclipses. The first successful observations were carried out during the total solar eclipse of 30 May 1965 (Delone & Makarova 1969). The measurements of interferograms showed that the profiles of emission lines have complicated shapes and can be decomposed into individual gaussian components. The observations of four subsequent eclipses confirmed these results.

The interpretation of interferometric profiles poses some difficulties compared with slit spectra, as the interferometric pattern is convolved with the coronal image. Therefore, the intensity at a given point of the profile would also reflect the brightness of the monochromatic corona and the white-light corona. We show in the following that the moving features persist even after the above factors are taken into account.

2. Observational data

We rely on some of the Fabry-Perot interferometric observations of the coronal emission lines obtained during five total solar eclipses: The line [Fe x] 6374 Å was observed on 30 May 1965 (Delone & Makarova 1969); on 7 March 1970 (Delone & Makarova 1973); on 10 July 1972 (Delone & Makarova 1972); and on 31 July 1981 (Delone, Makarova & Sykora 1983; Ushakov *et al.* 1984; Yaroslavsky *et al.* 1986). The line [Fe XIV] 5303 Å was observed on 22 September 1968 (Delone & Makarova 1975); and on 31 July 1981 (Ushakov *et al.* 1984; Yaroslavsky *et al.* 1986). At all expeditions the instrument used was the same double astrograph with two interferometric devices, so that one could obtain interferometric pictures in two lines simultaneously. The full widths at half maximum (FWHM) of interference filters were 15 or 12 Å at 5303 Å and 15 or 30 Å at 6374 Å. The interferograms were calibrated using a laboratory source (Krypton-filled discharge tube). The orange and green lines of krypton were recorded for calibration just before and immediately after the total phase. Usually the exposure times were in the range 3-30 s, but in 1965 it was 140 s as the sky was poor.

3. Results

The measurements of interferograms are described in detail elsewhere (e.g., Delone & Makarova 1969, 1975; Delone 1974). For the eclipses of 1965 and 1968 the slit of the densitometer was 12 arcsec × 3 arcsec; for the eclipses of 1970, 1972 and 1981, it was 3 arcsec × 3 arcsec (see Table 1). The instrumental profile did not spoil the spatial resolution appreciably, For example, in 5303 Å, FWHM of 0.2 Å corresponds to 5 arcsec. On the radial sections of interferometric pattern of the corona we traced the background continuum in the form of a smooth curve passing through the minima between the rings.

The positions of the maxima of the interferometric pattern for the eclipse of 1970 are shown in Fig. 1. Note the deviations of maxima from the mean ring. Similar shifts were noticed during other eclipses also, and in 1968 these were over protuberances. The magnitude of these shifts corresponds to the ascent of matter up to 60-70 ± 10 km s^{-1}. These shifts indicate the presence of line-of-sight velocities in the corona. Whereas such ring shifts are rare, most line profiles exhibit complicated non-gaussian forms, the profiles of red coronal line being more complicated than the green one. The complex structure of these profiles can be explained either by Doppler shifts and/or by brightness inhomogneities of monochromatic and white-light corona. The reality of the complicated form of the profiles was checked by comparing two independent, consecutive exposures for the eclipse of 1968; some examples are shown in Fig. 2. (The noise in this figure is not smoothed out; the signal-to-noise ratio is 7-10.)

Since the Fabry-Perot fringes are convolved with the spatial distribution of intensity, the inhomogeneities in the background continuum as well as line emission affect the profile.

We have attempted to study the effects of both these factors on the observed line profiles. The evaluation of white-light coronal inhomogeneities was made by a comparison of line profiles with the features observed in the white-light corona. The results are shown in Fig. 3.

Brightness inhomogeneities in emission lines can be seen till 0.2 of free spectral region (FSR), from the positions of line intensity maxima if the reflectivity of the interferometer plates is about 85 per cent. Line emission outside this is cut by the instrumental function. Inside 0.2 of FSR we can estimate the influence of inhomogeneities if we have a simultaneous direct photograph of the emission corona.

Table 1. Catalogue of Fabry-Perot (FP) and multislit (MS) observations of coronal emission lines.

Eclipse	Authors	Method	Spatial resolution ($arcsec^2$)
21 September 1941	Kalinijak (1949)	FP	Unknown
30 July 1954	Jarett & Klüber (1955)	FP	Unknown
12 October 1958	Jarett & Klüber (1961)	FP	Unknown
30 May 1965	Delone & Makarova (1969)	FP	3 × 12
	Liebenberg, Bessey & Watson (1975)	FP	1380
12 November 1966	Liebenberg, Bessey & Watson (1975)	FP	Unknown
22 September 1968	Delone & Makarova (1975)	FP	3 × 12
7 March 1970	Delone & Makarova (1973)	FP	c × 3
	Hirschberg, Wouters & Hazelton (1971)	FP	Unknown
	Marshall & Henderson (1973)	FP	0.1 $R_\odot$
	Livingston, Harvey & Doe (1970)	MS	100
10 July 1972	Kim & Nikolsky (1975)	FP	190
	Delone & Makarova (1973)	FP	10
30 June 1973	Bessey & Liebenberg (1984)	FP	
16 February 1980	Chandrasekhar, Desai & Angreji (1981)	FP	80
	Desai, Chandrasekhar & Angreji (1982)	FP	80
	Livingston & Harvey (1982)	MS	70
	Singh, Bappu & Saxena (1982)	MS	220
	Singh (1984)	MS	220
	Singh (1985)	MS	220
	Bhatnagar *et al.* (1982)	MS	Unknown
31 July 1981	Ushakov *et al.* (1984)	FS	10
	Yaroslavsky *et al.* (1986)	FS	10
11 June 1983	Singh (1984)	MS	5 × 9

At the eclipse of 1981 we have photographed the corona in 5303 Å and 6374 Å lines. The variation of emission-line intensity and the corrections required by it in the observed line profile are shown in Fig. 4 in the case of two examples. Note that the correction required is rather small.

The smoothed line-profiles, corrected for the influence of background continuum and emission line variations, can be decomposed into individual gaussian components as shown in Fig. 5. The number of components appear to be different for the red and green lines at a given location, the red line exhibiting more structure. The sizes of the moving feature are in the range 10-30 arcsec, which agrees with the range 5–35 arcsec

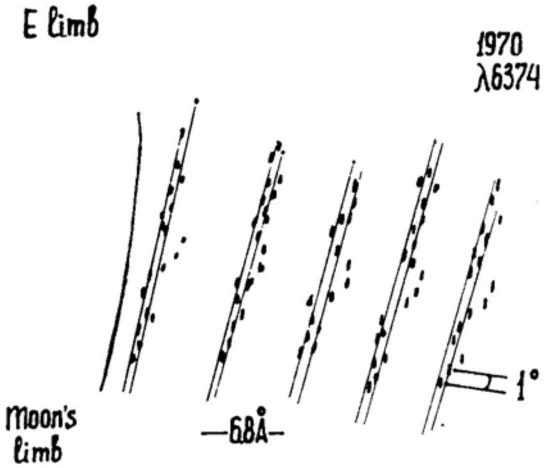

Figure 1. Positions of interference maxima showing ring shifts along a narrow coronal beam; 1970, 6374 Å.

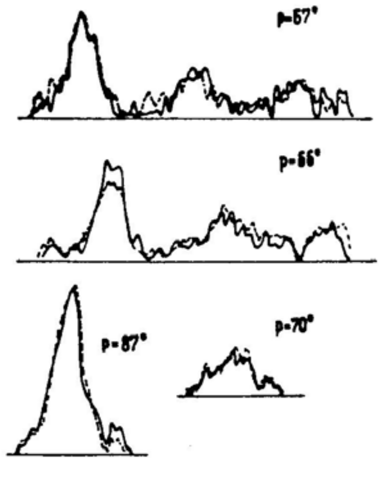

Figure 2. The profiles of the 5303 Å line in 1968:– – – t = 5^s;——1 = 3^s.

in the sizes of small-scale features measured in the emission-line corona (Picat *et al.* 1973; Fort & Picat 1975; Tsubaki 1975). The continuum variations affect the line profiles much more than the monochromatic ones. A large fraction of features persist even after these corrections are made.

4. Discussion

It is well-known that the brightness of solar corona decreases sharply with distance from solar limb. Assuming that moving features have their velocity vectors in the radial direction, the line profiles close to the solar limb would have a predominant contribution from features closer to the limb, moving perpendicular to the line of

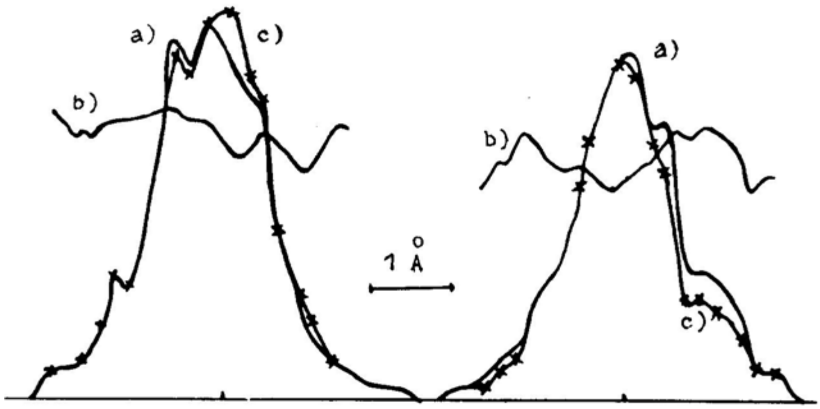

Figure 3. 5303 Å line profiles; (a) observed profiles; (b) monochromatic brightness distribution; (c) corrected profiles.

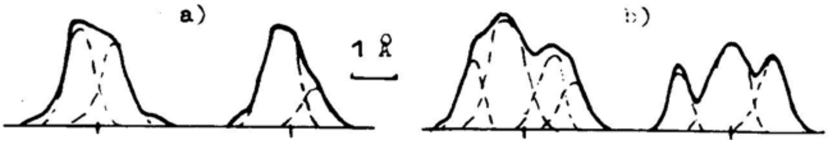

Figure 4. Examples of nongaussian profiles in 1981: (a) 5303 Å, (b) 6374 Å.

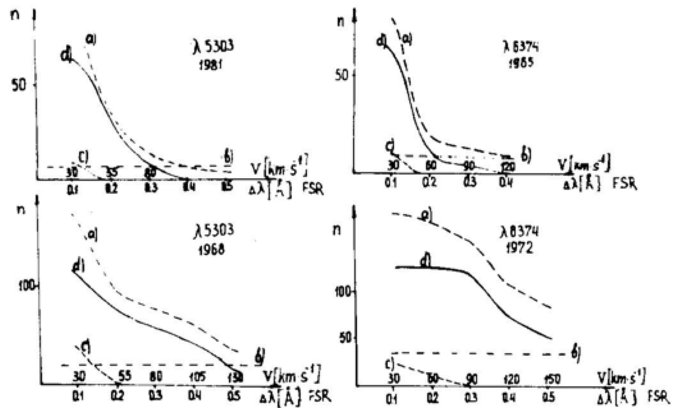

Figure 5. Velocity distribution of 5303 Å and 6374 Å features; (a) total number of moving features; (b) white light photometrically, induced features: (c) monochromatic photometrically induced features; (d) corrected velocity distribution.

sight. On the other hand, as one moves away from the solar limb, contribution from features moving at different angles would become more important. Thus we would expect the halfwidth of the profiles to increase with radial distance from the solar limb. This is clearly seen in Fig. 6 (a) providing indirect support for the existence of moving features: However, in the case of the corona of 1965 above an active region with very

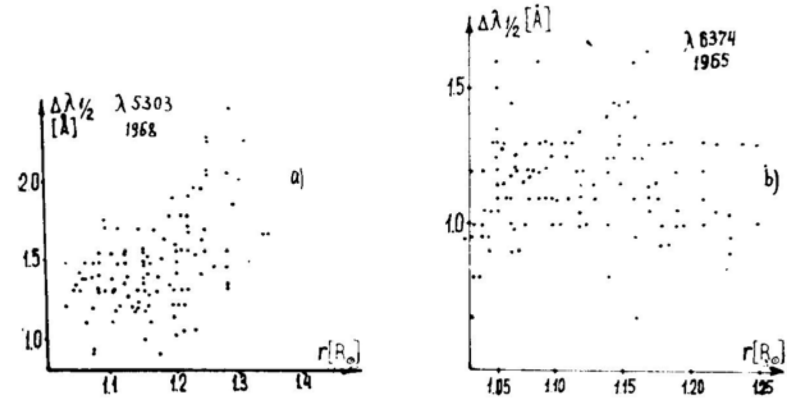

Figure 6. 5303 Å and 6374 Å halfwidth variation with distance from solar limb, (a) 1968; 5303 Å. (b) 1965; 6374 Å; the observations were near an active region.

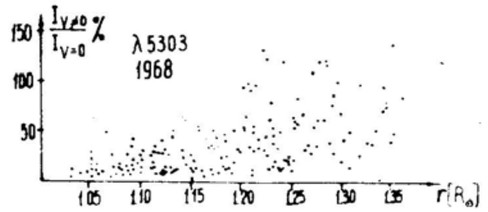

Figure 7. Dependence of the relative brightness of the moving features with distance from the solar limb; 1968; 5303 Å.

closed configuration, the halfwidth did not decline as sharply with radial distance (see Fig. 6b). A similar effect is seen in the intensities of moving features shown in Fig. 7.

Table 1 shows that most of the past results on coronal line profiles were based on rather poor spatial resolution (observational plus microdensitometric). We believe that increased spatial resolution would reveal the moving features. We quote Athay (1976); 'It is more generally believed that these phenomena [moving features in the corona] are present, as they are everywhere else in the solar atmosphere, but that we do not yet have sufficiently good observations to reveal them.'

Since the moving features add to the width of lines, one needs to exercise caution in estimating coronal temperature from the halfwidths of line profiles.

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