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# Fabry-Perot observations of the solar corona during total solar eclipses

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## 1. History

Although Fabry-Perot Spectroscopy was invented almost a century back (Fabry and Perot 1897) and was applied to astronomical problems as early as 1911, when Buisson, Bourget and Fabry took an interferogram of the orion nebula (Bussion et al. 1914); its first successful application to observe the coronal emission lines at high resolutions was possible only during the 1954 solar eclipse when Jarret and Kluber reported an interferogram taken in the emission line of [Fe XIV] at 5303 Å (Jarret and Kluber, 1955). Prior to that, a number of unsuccessful attempts were made (Wright and Curtis, Sproul Observatory Publ. no. 11; Carrol, 1947). Subsequent to the successful experiment of 1954, Jarret and Kluber (1961) observed the 1958 eclipse both in [Fe XIV] and the [Fe X] line at 6374 Å. On the basis of their observations they inferred coronal temperatures ranging from 2 million to 6 million degrees with a median value around 3.2 million. Subsequent to that a fairly good number of Fabry-Perot observations of the solar corona taken during total eclipses have been reported.

Delone et al. (1975, 1988) have taken coronal interferograms in both 5303 Å and 6374 Å lines during several eclipses. One of their important inference has been the existence of moving components in the corona on the basis of structures observed in the line profiles. Moving components with significantly large velocities (30-50 $kms^{-1}$) have been inferred from Fabry-Perot observations on 5303 Å coronal line during Feb. 1980 eclipse by the PRL group (Desai et al., 1982). However, for the same eclipse Singh et al. (1982), from their multislit spectra on 6374 Å [Fe X] line, do not find components with velocities beyond ± 11 $kms^{-1}$. For the same eclipse, Livingston and Harvey (1982) find components with velocities upto 12 $kms^{-1}$; from their multislit spectra. However, to explain the observed line widths of 5303 Å line, they do not rule out isotropic turbulence or superposition of isotropic flows upto 40 $kms^{-1}$ at some locations. It may be noted that Fabry-Perot interferograms have a much better coverage of the corona compared to multislit spectra. Although the velocities obtained by the PRL group for the 1980 eclipse appear to be on the higher side, and other workers in general agree on smaller values (Zirker 1987), there are a number of other Fabry-Perot observations which give comparably large values (Delone et al. 1988). Existence of moving components in the coronal plasma has remained a rather debated issue for quite some time. The magnitudes of velocities reported vary quite a bit, being dependent on the solar activity (Raju et al. 1993).

Kim and Nikolsky (1975) have also made Fabry-Perot observations in both [Fe XIV] and [Fe X] lines. They find a systematic increase in line-widths, outwards from the solar limb; which is interpreted as being due to increasing contribution from the nonthermal velocities in the corona. Bessey and Liebenberg (1984) observed in λ 5303 Å with a Fabry-Perot aboard an aircraft. Their instrument was pressure scanned, with Vidicon detector. Observations were made over a limited range of position angles and the observed linewidths, interpreted as temperatures give values in the range 2.2 million to 6 million degrees K. They also give a table of corresponding line to continuum ratios; inferred from intensities at the fringe minima. It is significant to note that, in general, the regions showing the highest temperatures in their data also show the lowest line to continuum values. Our own data taken during the 1980 eclipse (Gadag, India), the low contrast in FP fringes observed especially over active regions, has been interpreted as an evidence of existence of large macroscopic random velocities (Desai et al. 1991; Raju and Desai 1994). Hirschberg et al. (1971) have observed 1970 eclipse over a range of position angles covering a helmet streamer. Again, the line widths interpreted as temperatures give a value ranging from 2.5 million to 6 million degrees, with a systematic change from outside to the core.

Fabry-Perot interferograms have been taken by the Physical Research Laboratory team in 1980 (in 5303 Å); in 1983 (5303 Å and 6374 Å) and 1995 (in 5303 Å, 6374 Å). In addition, during the 1995 eclipse a Fabry-Perotgram was also taken in [Ca XV] 5694 Å with a low resolution (FWHM 1.2 Å) etalon. The line profiles, especially in 5303 Å taken during the 1980 eclipse definitely confirm the existence of moving components in the corona (Chandrasekhar et al. 1991). During 1980 eclipse, at one location fringes were actually split, showing a differential mass motion ~ 70 $kms^{-1}$ (Chandrasekhar et al. 1981). Our results also indicate that the large line widths do not necessarily imply high temperatures and could largely be due to macroscopic random velocities in the corona (Raju and Desai 1994).

## 2. Line profiles and the coronal heating

A major aim in studying the coronal emission line profiles to explore, to what extent such a study can help towards illucidating the coronal heating processes. Although it is generally agreed that the corona is heated magnetically (at least so far as solar type stars are concerned), specific mechanism (or mechanisms) through which the energy of the photospheric motions is carried to, and dissipated at the coronal heights remains a much debated issue.

Three major classes of mechanisms have been invoked (Zirker 1993).

i) These involves heating through dissipation of MHD waves, especially Alfven waves. Typical transit time for an Alfven wave along a loop is ~ 100 seconds, which is short compared with the time scales in photospheric motions; so the energy contained in the power spectrum of photospheric motions; at short time scales could be responsible. [see also Pasachoff (1991) for evidence of intensity oscillations]. There is also some difficulty with finding an efficient dissipation mechanism. Damping of resonant surface waves in the regions of strong field gradients (Ianson 1978, 1984) seems the most effective.

Observationally, this should imply existence of hot sheath around a loop, but confirmation of such a phenomenon would need very high spatial resolution, which could be provided by a suitable space mission. Existence of nonthermal broadening in the transition region and the coronal emission lines [~20-25 $kms^{-1}$ in quiet corona, 40-50 $kms^{-1}$ in active corona] have been proposed as a support, but these do not seem to be unique to the wave heating; and could also be explained by impulsive heating (Zirker 1993). Heating through direct Joule dissipation of field aligned currents require strong currents flowing in narrow filaments, which also could in principle be confirmed by high spatial resolution observations. Dissipation in transverse currents (in neutral sheet) associated with reconnections would specifically result in impulsive heating; and release of energy in kinetic motions in the plasma.

Our own 1980 data show a possible scenario in which such a mechanism could be operative. This is shown in Fig. 1, where three locations in the corona are identified. Two of them marked "H" locate regions where the interferogram fringes show high contrast (implying low random velocities) and a region marked "L" where the fringes show low contrast implying large random velocities (Desai et al. 1990). The regions are located on a structural map (Loucif and Koutchmy 1989), which indicate coronal field configuration; and one can see that reconnections occurring over region "L" are quite likely [Although contrast of Fabry-Perot fringes also depends on the width of the observed line, it can readily be verified that for a reasonable range for the coronal temperatures (2 to 5 million degrees), the increased Doppler width cannot account for the observed contrast reduction (Raju and Desai, 1994)].

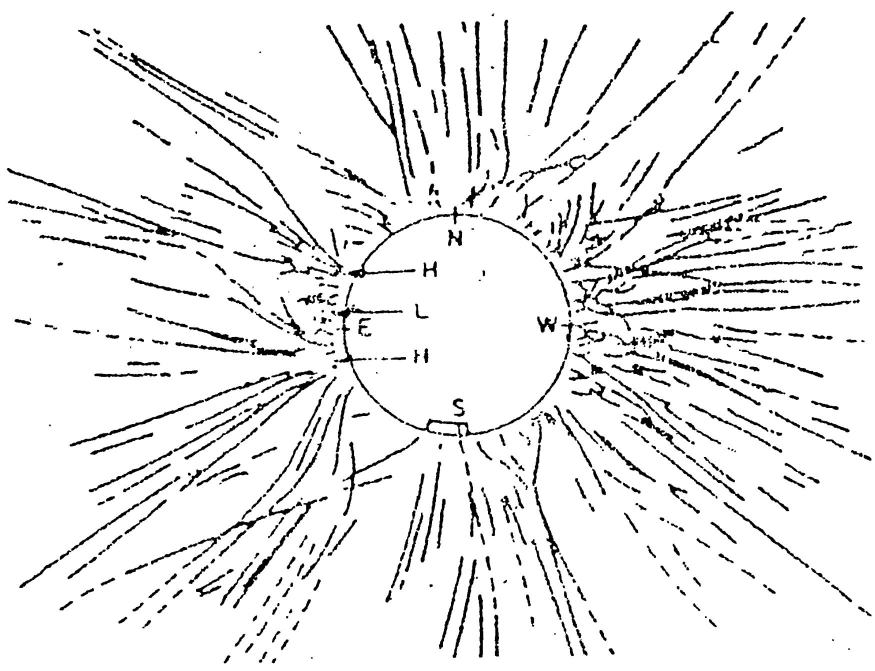


**Figure 1.** Location of some high and low fringe contrast regions on the map of coronal structures for 16 Feb. 1980 eclipse. Structure map from Loucif M.L. and Koutchmy S. (1989).

Third type of mechanism invoked for the coronal heating is MHD turbulence. At smallest scales the velocity field is turbulent and dissipative. This differs from reconnection related heating which results from thermalization of high speed bulk velocity produced at a specific site.

It is clear from the above discussions that, one needs observations with higher temporal and spatial resolution to decide between different plausible heating mechanisms and such observations are most likely to be provided by space borne instrumentation, still however, a critical look at previous line profile studies, and appropriately planned specific experiments during total eclipses could also provide a valuable information.

It was with their perspective that we carried out an experiment during the Oct. 1995 eclipse in which we took a Fabry-Perotgram in [Ca XV] emission at 5694 Å. In this experiment, the low order FP fringes were taken with a piezo controlled etalon (FSR ~ 35 Å; FWHM 1.2 Å) with [Ca XV] prefilter of bandwidth 20 Å. The fringes were centred with respect to the solar disc with the innermost 5694 Å transmission fringe centred at 1.05 R; and scaled such that its FWHM of 1.2 Å covered 1.10 R to 1.15 R. It was also planned to take two more FP grams with the fringe peak shifted to 1.05 R and 1.10 R respectively, but the brevity of totality permitted only the first exposure. Purpose of the experiment was to i) Locate regions of emission in [CA XV] as a indication of high temperature corona and ii) to get velocity resolved information (albeit with low velocity resolution ~ 20 km $s^{-1}$) on the emitting region.

Interferogram in 5303 Å were also taken with off-centred fringes as in earlier experiments. 5303 Å interferogram was registered much weaker compared with 80 and 83 interferograms and only along equatorial directions; 6374 Å interferogram was registered very well over the entire corona. Analysis is still under progress.

## 3. Conclusion

Coronal interferograms taken mostly in 5303 Å and 6374 Å with Fabry-Perot etalons during total solar eclipses have provided very valuable informations in the past on the temperatures, mss motions and state of turbulence in the coronal plasma. During future eclipses, experiments planned with very specific objectives, especially studying line profiles in relation to observed coronal structures from specific regions, could be very useful towards understanding coronal heating.

Before concluding, it may be pointed out that Fabry-Perot observations on the corona could be very useful even under non-eclipse conditions. In that connection, Bonaccini and Smartt (1988) have considered using a solid Fabry-Perot made of electro-optical material Lithium Niobiate. With the etalon plates cut parallel to the optic axis the material would show two refractive indices "e" index for electric vector polarized parallel to the symmetry axis and "o" index for the perpendicular polarization. Light with "e" index is electro-optically almost insensitive whereas that with "o" index can be voltage scanned ~ 1 Å per kilovolt. This way one can scan over a coronal line compared against a constant continuum background.

We have developed an alternative technique for discriminating line against continuum (Desai et al. 1979), which has been used successfully to detect [OI] 6300 Å dayglow emission (Narayanan et al. 1989). This involves wavelength modulation using suitable masks at the focal plane of a Fabry-Perot. A modification of the method could be used where the field of view is not uniform (as in corona) by using telecentric optics as in insect eye camera devised by Courtes (Meaburn 1976). Such an approach could perhaps be tried out also for optical detection of stellar coronae, (Full details of proposed instrumentation is planned to be published).

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