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The Excitation Mechanism of [Fe XIV] 5303 Å Line in the Inner Regions of Solar Corona

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Abstract. The line intensity of the green coronal line and the continuum intensity are derived from the filter and white light photographs of the solar corona obtained during the 1980 total solar eclipse. Ratio of the line to continuum intensity is plotted against the radial distance $r(=R/R_0,$ R_0 is the solar radius), in various position angles . A simple model assuming an electron density dependence of the line and continuum intensities suggests a dominant collisional mechanism for the excitation of the line in the innermost regions (~ 1.4 R_0). The measured line to continuum ratio tends to a constant value at different radial distances in different position angles. The constancy of the measured line to continuum ratio indicates significant radiative excitation beyond 1.4 R_0, in some of the position angles.

Key words: solar corona—emission lines—excitation mechanism

1. Introduction

The green coronal line at 5303 Å of [Fe XIV] is one of the strongest lines emitted by the solar corona in the visible spectrum. The excitation mechanism of this line is not very well known, especially with reference to the relative contributions of collisional and radiative processes at various solar altitudes and position angles (Zirin 1988; Singh 1985). Here we make an attempt to determine the dominant mechanism of the excitation of this line. A detailed theoretical calculation can be seen in Raju & Singh (1987). However, the estimation of the continuum intensities based on the levels of minima between Fabry-Perot fringes can be subject to significant errors in the presence of large random velocities in the corona (Desai *et al.* 1990). We derive the line to continuum ratios based on a narrow band filtergram and a white light picture of the corona obtained during the 1980 eclipse.

2. Observations

A filtergram of the solar corona was obtained in the green coronal line using an f/10 Cassegrain focus of a 20-cm diameter Celestron-8 telescope during the 1980 total solar eclipse. The image was recorded on a precalibrated TriX 35 mm film. Details of the filter are as given below.

Type: interference filter (Spectro Film Inc.)
Size: circular, 1 inch diameter
Bandwidth (FWHM): 10 Å
Peak wavelength: 5300 Å.

The continuum picture was taken using a precalibrated PlusX 35 mm film and a Questar 9 cm telescope. Photographs of the filter and the continuum pictures are shown in Figs 1 (a) and 1 (b).

3. Analysis

Both the filter and white light photographs were digitized using a PDS microdensitometer with a pixel size of 20 μm × 20 μm. . The digitized photographs were analyzed on a computer. To get radial scans along different position angles, first the solar centre in each frame was determined. This was done by displaying the digitized picture in an image processing system and noting down the coordinates of the lunar limb and then fitting a circle to it. Using the known diameters of the lunar and solar discs during this epoch, which were 33′23″ and 32′38″ respectively, appropriate corrections were performed to get the solar parameters. Matching of the two frames was also carried out at this stage to get the corresponding directions in the two frames. Radial scans in various position angles were obtained using a computer software .Photographic densities of three adjacent directions of 0.5° angular separation were averaged at each radial point in order to minimize the noise. Photographic densities were converted into relative intensities using a photographic characteristic curve.

4. Discussion

In the filter photograph, the measured intensity is given by

$$E_1 = \alpha I_1 + \beta I_c$$

and in the continuum picture, the measured intensity is

$$E_c = \gamma I_c$$

where α, β, γ are constants depending upon the instruments as well as the exposure time, α and β are proportional to the fractional transmission of the line and continuum intensities through the filter respectively and γ is a proportionality constant. The ratio (α / β) is obtained from the transmission profile of the filter; $\alpha / \beta = 0.08$. Because the white light picture was taken with a polarizer, to obtain the intensities corresponding to the unpolarized frame, a correction was made, taking into account the radial variation of polarization in the solar corona (Athay 1976) and the known orientation of the polarizer. $I_{1,}$ is the integrated emission intensity across the line while I_c is the continuum intensity per angstrom.

$$\frac{E_1}{E_c} = \frac{\alpha I_1}{\gamma I_c} + \frac{\beta}{\gamma}. \tag{1}$$

The observed E_1/E_c against r for different position angles are plotted in Figs 2(a)-(h). The behaviour of I_1/I_c can be deduced from these plots.

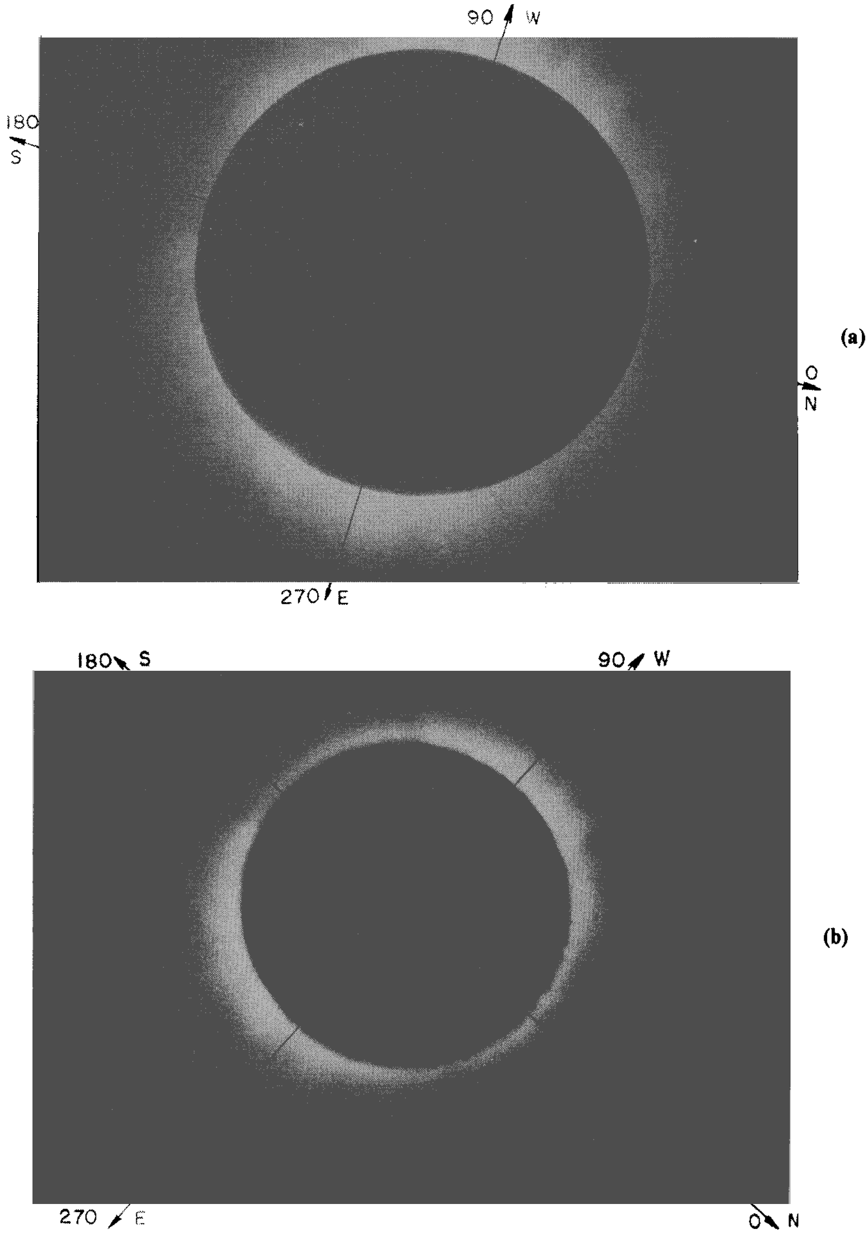

Figure 1(a)—(b). Filter and white light photographs of solar corona obtained during 1980 February 16. Position angles are indicated.

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The radiative component of I_1 is given by

$$I_1(\text{rad})\,(r) = c_1 \int_{-\infty}^{\infty} n_e(r)\; w(r)\,\text{dl}, \tag{2}$$

the collisional component of I_1 is given by

$$I_1(\text{col})(r) = c_2 \int_{-\infty}^{\infty} n_e^2(r)\,\text{dl}. \tag{3}$$

Then,

$$I_1(r) = I_1(\text{rad})(r) + I_1(\text{col})(r). \tag{4}$$

The continuum intensity is

$$I_c(r) = c_3 \int_{-\infty}^{\infty} n_e(r) w(r)\text{dl}. \tag{5}$$

In Equations (2) through (5)

$$c_1 = R_0 \frac{g_j}{g_i}\left[\exp\left(\frac{h\nu_{ij}}{kT_R}\right)^{-1}\right]^{-1} \frac{\text{N(Fe XIV)}}{\text{N(Fe)}}\frac{\text{N(Fe)}}{\text{N(H)}} 0.83 A_{ij} \frac{\text{h}\nu_{ij}}{4\pi},$$

$$c_2 = R_0 \left[8.63 \times 10^{-6} \frac{\Omega_{\text{eff}}}{T_e^{1/2} g_i} \exp\left(-\frac{h\nu_{ij}}{kT_e}\right) \frac{\text{N(Fe XIV)}}{\text{N(Fe)}}\frac{\text{N(Fe)}}{\text{N(H)}} 0.83 \right.$$

$$\left. + 1.38 \times 10^{-9} \times 0.83 \right] A_{ij} \frac{h\nu_{ij}}{4\pi}$$

and

$$c_3 = R_0 J_0^{\lambda} \sigma_e.$$

where g_i g_j are the statistical weights of the lower and upper levels of the transition under investigation, T_R is the radiation temperature of the photosphere, N is the abundance by number, A_{ji} is the spontaneous transition probability, Ω_{eff} is the effective collision strength, T_e is the electron temperature, J_0^{λ} is the mean solar intensity at λ 5303, and σ_e is the Thomson scattering cross section. It can be seen that c_3 is a constant while c_1 and c_2 are constants for an isothermal corona. These constants may be evaluated from the various factors available in the literature (Mason 1975; Jordan 1969). $w(r)$ in Equation (5) is the geometrical dilution factor. The electron density $n_e(r)$ is tabulated by Newkirk (1967) and Dürst (1982). The integrals were evaluated within the limits $-\ 2R_0$ and $+\ 2R_0$, since no appreciable contribution to the line intensity was found to come from beyond these limits.

Line to continuum intensity ratios were calculated using the electron density distribution given by Durst (1982) for equatorial solar maximum corona and for an average coronal temperature of 2 million degree Kelvin. The result is shown in Fig. 3. I_1/I_c values for radiative and collisional mechanisms are plotted separately. It can be seen that for pure radiative excitation, the ratio I_1/I_c is constant while for pure collisional excitation, it decreases with increasing radial distance (Billings 1966; Singh 1985; Raju & Singh 1987). Fig. 2 shows that $E_1\,/E_c$ becomes constant at different radial points in different position angles. $E_1\,/E_c$ becoming constant with respect to r indicates either the domination of radiative excitation or ($\alpha I_1 \ll \beta I_c$). In Table 1, we have tabulated the values of E_1/E_c at the respective radial distances when they become constant. Extent of the green line emission as recorded by the Fabry-Perot

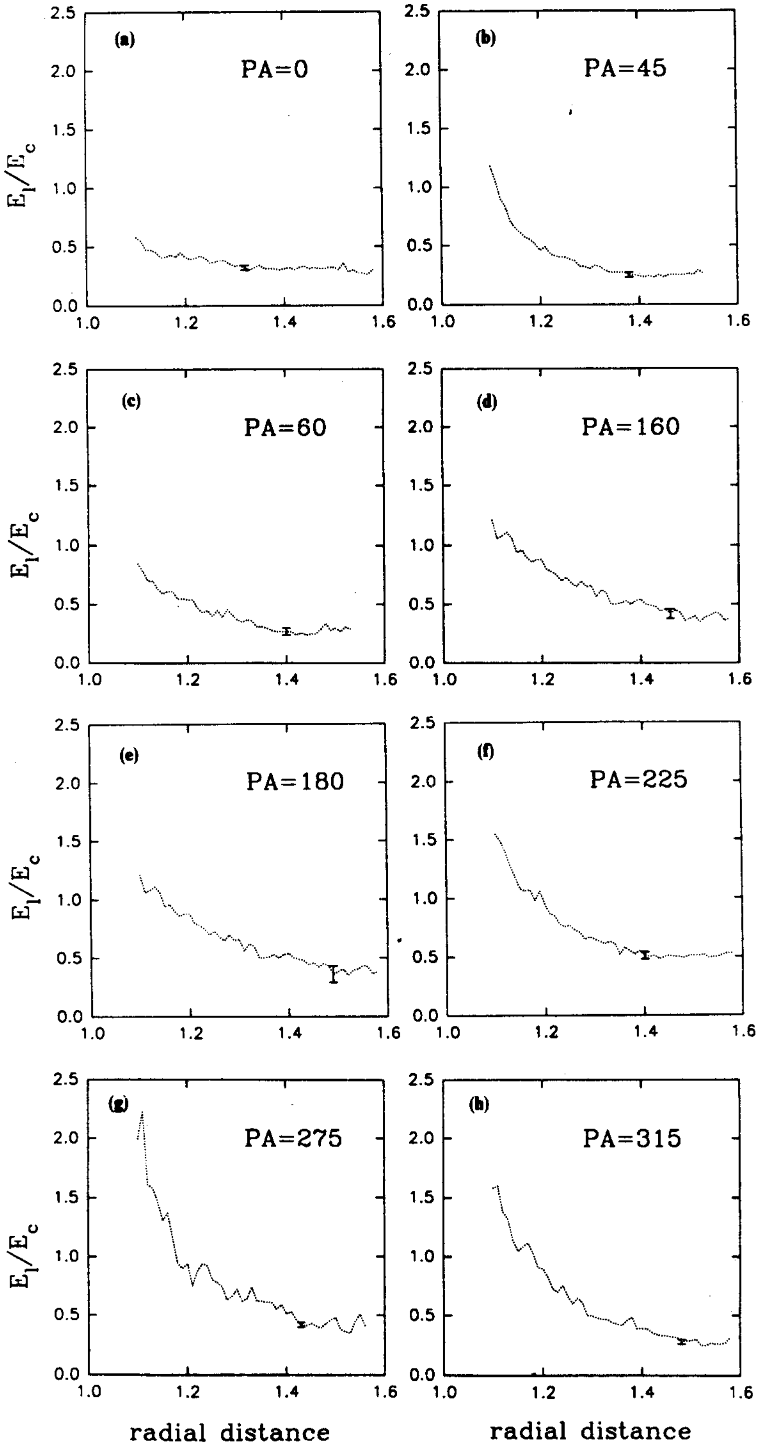

Figure 2(a)—(h). The measured line to continuum intensity ratio in different position angles. Measurement errors are indicated at those radial points where the ratio E_1/E_c becomes constant.

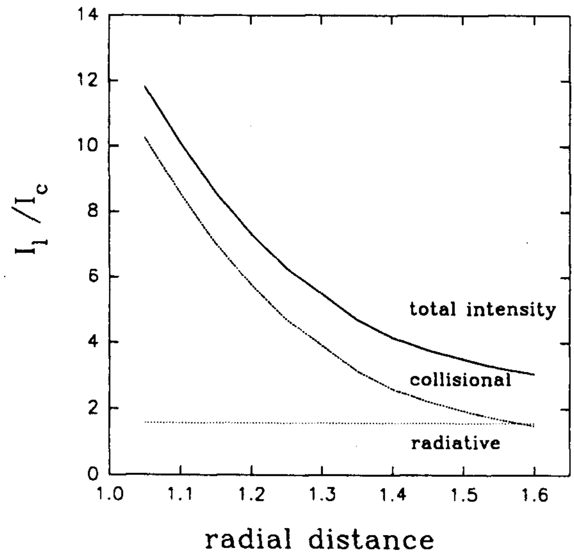

Figure 3. Computed values of line to continuum intensity ratio for equatorial, isothermal (2 MK) solar m aximum corona. The collisional and radiative contributions as well as the total intensity are marked.

Table 1. Columns denote the position angle, the radial points where E_1/E_C become constant in units of r, the ratio (E_1/E_c value of E_1 in arbitrary units and the interferogram extent in units of *r*, respectively.

PA	E_l/E_c = const at (*r*)	E_l/E_c	E_l	Interferogram extent
0	1.32	0.32 ± 0.02	3.89	1.26
45	1.38	0.25 ± 0.02	2.45	1.36
60	1.40	0.25 ± 0.03	2.00	1.41
160	1.46	0.27 ± 0.04	1.45	not available
180	1.49	0.39 ± 0.07	1.15	not available
225	1.40	0.50 ± 0.03	4.68	not available
275	1.43	0.41 ± 0.02	6.31	1.32 ?
315	1.48	$0.27 + 0.02$	2.75	1.41

interferometric observation of the solar corona of 1980 February 16 is given for comparison (Chandrasekhar 1982).

The constant value of E_l/E_c observed at different azimuths (i.e.β/γ) has no significant variation above the uncertainties of the measurement. However, at two specific az`imuths (PA 225 & 275), it is distinctly larger. This could be due to the contribution of radiative excitation to the line intensity. In these azimuths, the value of E_l is larger than the same for other azimuths, at constant E_l/E_c,. If the high values of E_l/E_c *are* due to the contribution of line intensity, one would expect an extended line emission in the interferogram at these position angles. Unfortunately, out of the two position angles, no data was available in one of them and in the other, recorded emission was restricted by vignetting effect. The higher value of E_1/E_c may be due to the significant contribution from radiative excitation and the favourable temperature at these azimuths. It should be kept in mind that the line intensity is sensitive

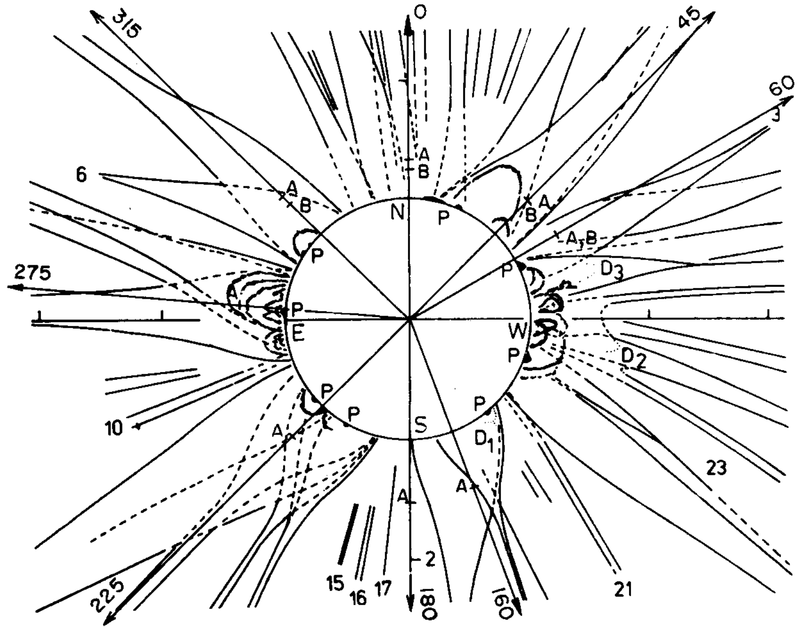

Figure 4. Directions for which E_I/E_c are plotted against *r in* Fig. 2. Points A and B denote the radial points, where E_I/E_c become constant and the extent of λ 5303 emission as seen from interferogram, respectively.

to the temperature of the region observed and the green line intensity reaches a maximum at a temperature of 1.8×10^6 K (Jordan 1969).

Fig. 4 (reproduced from Rusin & Rybansky 1982) shows the structures seen in solar corona during the 1980 total solar eclipse. The indicated directions are those for which values of E_1/E_C are plotted in Fig. 2. The radial points where the ratio E_1/E_c becomes constant are shown along with the points up to where the λ 5303 emission is seen in the interferogram. It can be seen that the behaviour of line to continuum ratios is different in various coronal regions. In the open north polar region, the measured line to continuum intensity becomes constant much earlier than the other position angles.

5. Conclusions

Excitation mechanism of the green coronal line is studied from the measured line to continuum ratios in various coronal regions. The large variation of the measured line to continuum ratios in different azimuths shows the inhomogeneous nature of the corona. The dominant line excitation mechanism is collisional in the inner coronal regions (up to ~1.4 R_0). Whereas constancy of the E_1/E_c ratio and the interferogram do not indicate significant contribution to the line intensity by radiative excitation over the collisionally dominated excitation at most azimuths, we find some evidence for this at two of the azimuths. This could be due to the exceptionally favourable temperatures for Fe XIV number density.

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