The Effects of Electron Scattering on the Si II 1816 Line in the Solar Chromosphere

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Abstract. We have considered the formation of Si II 1816 line in the solar chromosphere. The VAL model has been adopted as the input for the electron density and temperature. These preliminary calculations show that there are measurable changes in the profile shape of this line due to electron scattering.

1. Introduction

Auer and Mihalas (1968) studied some parametrized models including electron scattering in spectral line calculations. If the electron scattering coefficient exceeds continuous absorption, they obtained measurable changes in the line profile due to electron scattering.

Si II 1816.92 ($3s^2 3p\ ^2P^0(J=3/2)$ - $3s3p^2\ ^2D(J=5/2)$) (Wiese et.al, 1969) line has optical thickness of $\sim 10^4$ in solar atmosphere. Therefore radiative transfer effects are important. The ratio of electron scattering coefficient to line centre absorption coefficient for this line exceeds the ratio of continuous opacity to line centre opacity in solar chromosphere. So electron scattering may play an important role. Earlier theoretical work by Tripp et.al (1978) on this line could not match with observations. Study of Si II and Si III is important because they are formed in chromospheric temperatures and turbulent velocities can be inferred from them.

2. Electron scattering redistribution function

The angle averaged electron redistribution function is given by (Auer and Mihalas, 1968),

$$R^e(x', x) = \left(\frac{1}{w}\right) ierfc\left(\left|\frac{x - x'}{2w}\right|\right). \tag{1}$$

Here w is the ratio of electron to atomic Doppler widths and is given by $w \simeq 43A^{1/2}$ where A is the atomic weight of the atom under consideration. x' and x are the frequencies of the absorbed and emitted photons expressed in atomic Doppler units. ierfc (z) is the integral of the complementary error function. Over a few atomic Doppler widths, $R^e(x', x)$ remains constant. Therefore the contribution from noncoherent electron scattering remains constant in the Doppler core of the line. The noncoherent electron scattering may influence the wing to very large atomic Doppler units away form the line centre due to the large ratio of electron to atomic Doppler widths.

3. Method of Solution

We have considered only two level atomic model for which the radiative transfer equation including noncoherent electron scattering is given by

$$\pm \frac{\mu}{\chi_{l_0}(z)} \frac{dI(x, \pm\mu, z)}{dz} = -[\beta(z) + \phi(x)]I(x, \pm\mu, z) + \epsilon(z)\phi(x)B(z) + \beta_c(z)B(z)$$
$$+ \frac{1-\epsilon(z)}{2} \int_{-1}^{1} \int_{-\infty}^{\infty} R^a(x', x)I(x', \mu', z)dx'd\mu' + \frac{\beta_e(z)}{2} \int_{-1}^{1} \int_{-\infty}^{\infty} R^e(x', x)I(x', \mu', z)dx'd\mu'.$$

Here

$$\beta_e(z) = \frac{\sigma_e(z)}{\chi_{l_0}(z)}, \quad \beta_c(z) = \frac{k_c(z)}{\chi_{l_0}(z)}, \quad \text{and } \beta(z) = \beta_e(z) + \beta_c(z).$$

All the symbols have their usual meaning. We have used Voigt function for $\phi(x)$ with damping width $a = 10^{-3}$. $R^a(x', x)$ is the usual redistribution function and we have used $R_{II}(x', x)$ in our calculations. This problem has symmetric solution with respect to the line centre and so we need to consider only half the frequency grid. Coverage in the wings has been extended to 4 electron Doppler widths. To solve the above problem, we employed the Discrete space theory of Grant and Hunt (1969). For the angular integration in the transfer equation, we have used two-point Gaussian quadrature. In evaluating the scattering integral over the atomic redistribution function R_{II}, we used the natural cubic spline representation of the radiation field (Adams et al., 1971). We have used 32 point frequency quadrature. The redistribution function was evaluated using the procedure given by Ayres(1985). Thus we could extend our calculations to large Doppler units from the line centre. Following Auer and Mihalas (1968), the interval $[0, \infty]$ for the electron scattering is limited to $[0, x_1]$ and the remainder is handled analytically assuming $I_x = I_{x_1}$ for $x > x_1$, so that I_x may be taken out of the integral. We have modified the computer code of Peraiah (1978) suitably to solve the radiative transfer equation including electron scattering.

4. Results and discussion

We have used the VAL (1981) solar atmospheric model C as suggested in their paper for the calculation of Si II lines in quiet sun. Taking electron density, temperature and other parameters from this model, we calculated the continuous opacity, line opacity, collisional excitation parameters by Auer et al.(1972) code. We find that the electron scattering dominates over continuous opacity in the chromosphere for this line. These values were read as input into the radiative transfer calculation. We have assumed two level atomic model with frequency dependent PRD source function in our calculation. We have plotted in figure 1 the calculated Si II 1816 line in wavelength scale assuming uniform microturbulent velocity of 6 km/s in the line forming region. We find that the electron scattering when included in the calculation gives better agreement with observed line (Nicholas et.al, 1977) at $\mu = 0.79$. These preliminary calculations show that VAL model fits Si II 1816 line. But one has to do multilevel calculations before coming to a definite conclusion. Tripp et al.(1978) calculated Si II and Si III lines in the solar chromosphere using multilevel CRD formalism. They could not get limb darkening for 1816 A line. Their computed profiles show self-reversed core but the observed profiles are emission lines. Our profiles show emission in the core though we could not get limb darkening. The emission is increased in the wings by electron scattering which injects the photons from the Doppler core.

5. Conclusions

Within the limitation of the assumption of two level atomic model, for solar Si II 1816 line, we find that the noncoherent electron scattering when included in the calculation with VAL model C gives good agreement with the shape of the observed profile. But one has to incorporate multi-level atomic model with cross redistribution functions in the calculations before arriving at a definite conclusion.

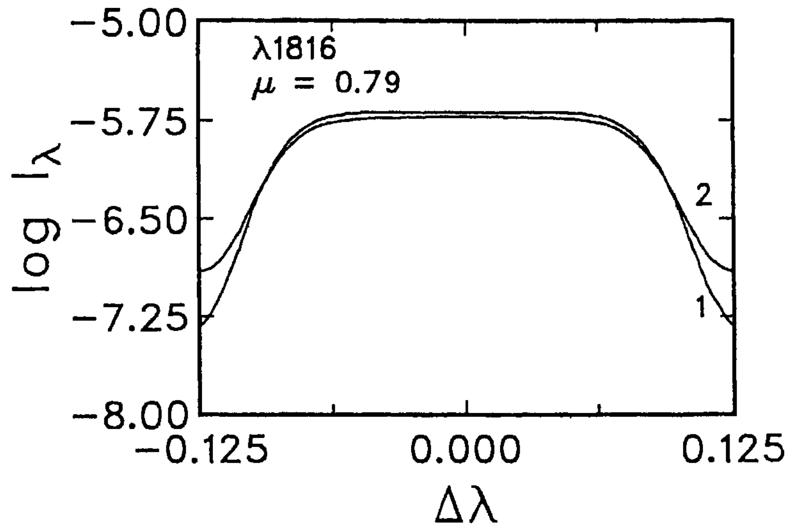

Figure 1. Specific intensity I_λ is plotted against the wavelength difference $\Delta\lambda$ from the line centre. Calculations were made with the VAL model C for Si II 1816 line in the solar atmosphere. 1 identifies the case without electron scattering and 2, the case with noncoherent electron scattering.

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