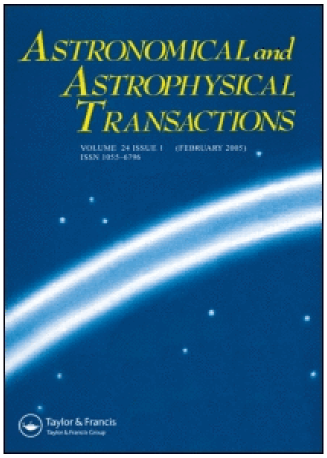

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THE Fe I AND Fe II LINE EMISSIONS IN SOLAR FLARE MODELS

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Two flare models are calculated which simultaneously interpret the observed profiles of Balmer lines H_α, H_β, H_δ, and the lines of Fe I, Fe II, Ti I, Ti II for two flares of importance 2 and 3. It is found that the emission of Fe I and Fe II lines originates in the photosphere where column number density $N = 3 \times 10^{23}$. An agreement between theoretical and observed profiles for Fe I and Fe II lines was found possible only for flare models with decreased or increased (compared with indisturbed values) density of photospheric layers. The derived models have very extended photospheric layers – up to 1600 km.

KEY WORDS Sun, flare

1 INTRODUCTION

Hydrogen Balmer line profiles have been used for research on solar flares for many years. However, metal line investigation had a qualitative character until recently. Emission of the metal lines is observed practically in all flares of levels 2 and 3. Most of them are Fe I and Fe II lines. The question of the depth formation of metal line emission is not very clear, although most workers suppose a deeper formation of metal line emission in comparison with the hydrogen emission. This question is interesting in connection with the energetic balance of the lower layers of the flare. The energy emitted in some hundred metal lines is equal or exceeds the hydrogen line energy value. If the metal emission depth is great, the problem of flare energetic balance includes the same difficulties as continuum emission interpretation (Abordarhan and Henoux, 1986). The significant perturbances in photospheric layers during the flares are found in Alikaeva *et al.* (1983, 1986, 1995) and Baranovsky and Koval (1981, 1982). Here we investigate the problem of Fe I and Fe II emission using the observations of two flares of level 2 and 3.

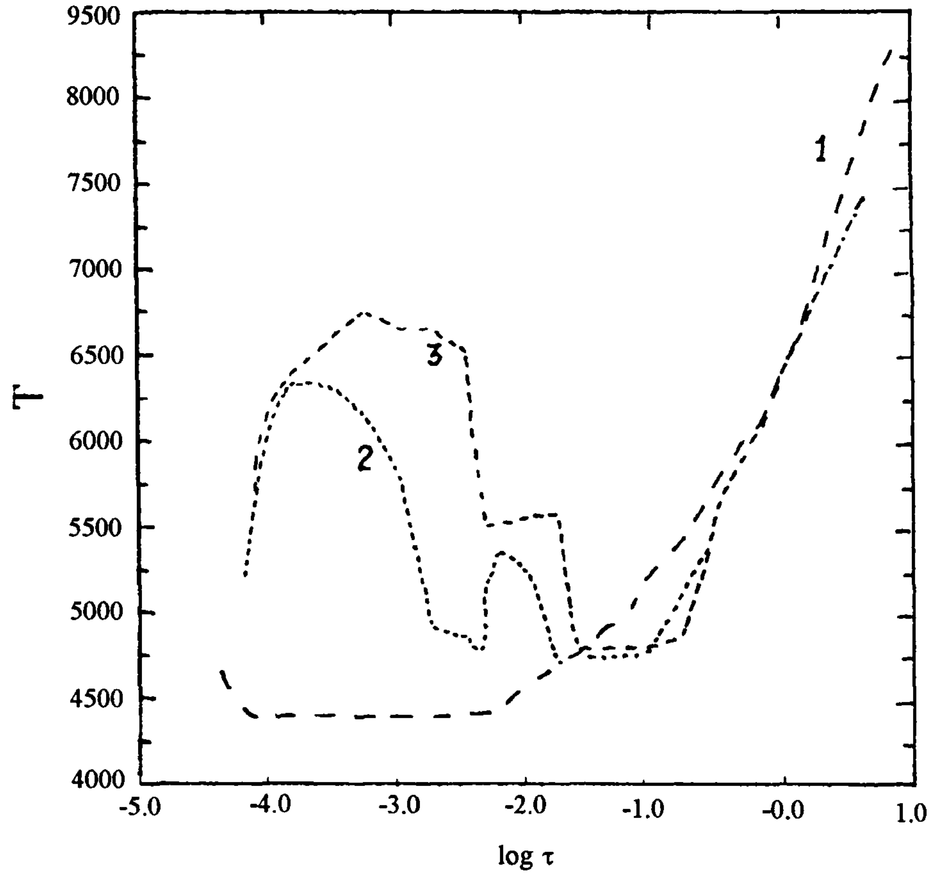

Figure 1 The temperature versus optical depth dependence for the solar flares of importance 2 and 3. Curve 1 fits the undisturbed photosphere model, curves 2 and 3 represent calculated models for flares of importance 2 and 3 accordingly.

2 OBSERVATIONS AND COMPUTATIONS

The flare spectra were obtained at the Tower Solar Telescope of the Crimean Astrophysical Observatory July 8, 1959 and October 11, 1960 using the echelle spectrograph. The flares were situated in the penumbra at distances from the solar disk centre $r = 0.7$ and 0.74. The photometry of the spectral was performed on the microphotometer in the direct intensities. The photometric profiles of the following lines were used for the investigation: H_α, H_β, H_δ, Fe I – 5124, 5233, 5269, 5328 Å; Fe II – 4924, 5018, 5169, 5198, 5235 Å; Ti I – 5025, 5026, 5145, 5147 Å. Our aim was to find the models (i. e. a dependence of temperature T, density N_H and turbulent velocity V_t upon the height H) which would give good agreement between observed and calculated profiles for all the lines that were examined. We also included the

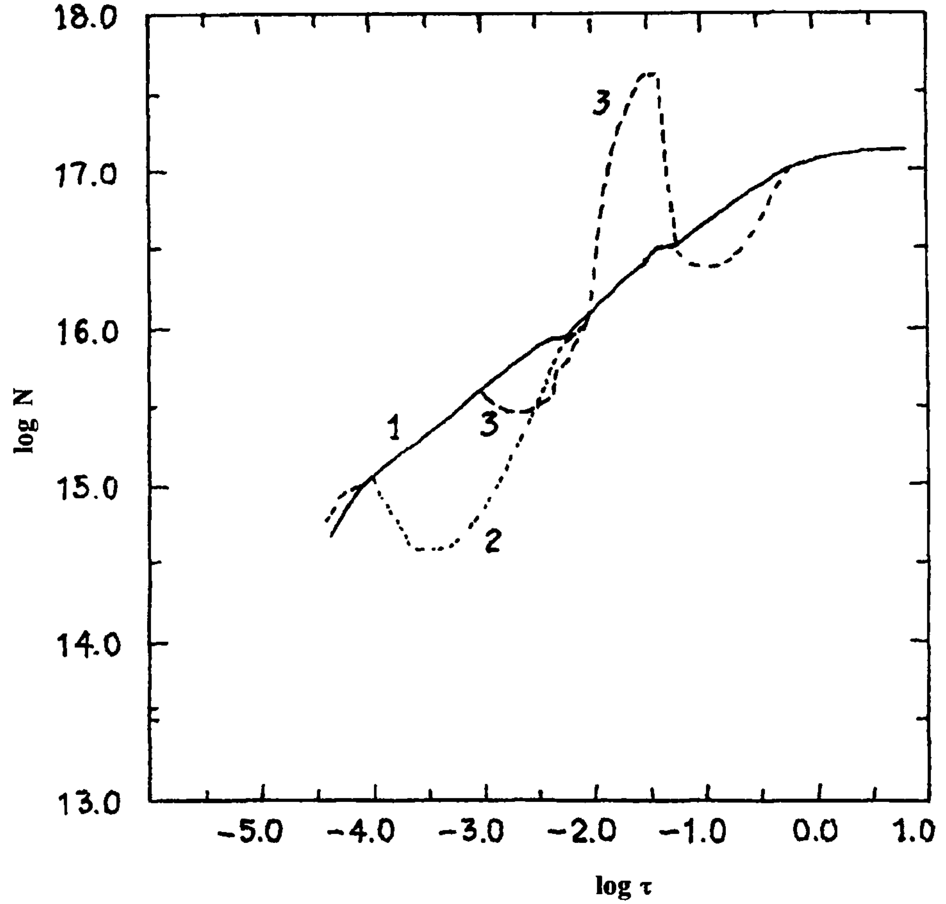

Figure 2 The density N_H versus optical depth dependence for the solar flares of importance 2 and 3. The curves are the same as in Figure 1.

lines of Ti II (5337, 5154Å) for the sake of obtaining more reliable models of photospheric layers. The calculation of Balmer line profiles was done using a non-local thermodynamic equilibrium (LTE) program. For the calculation of the weaker lines of Fe I, Fe II, Ti I, Ti II the simplified program proposed by Baranovsky (1993) was used. As the first stage of the work we calculated all profiles for the models of undisturbed chromosphere and photosphere and compared them with observed undisturbed line profiles. In this way we checked the atomic parameters for the metal lines and the calculation procedure. The Balmer lines were used for the construction of chromospheric models. The thus derived models gave too low emission for Fe I and Fe II lines if the photospheric layers remained unchanged.

Next we tried various values of temperature T, density N_H and turbulent velocity V_t in the photospheric layers. The evaluation of models was done by a trial – and error method. The calculations were carried out for a great number of models

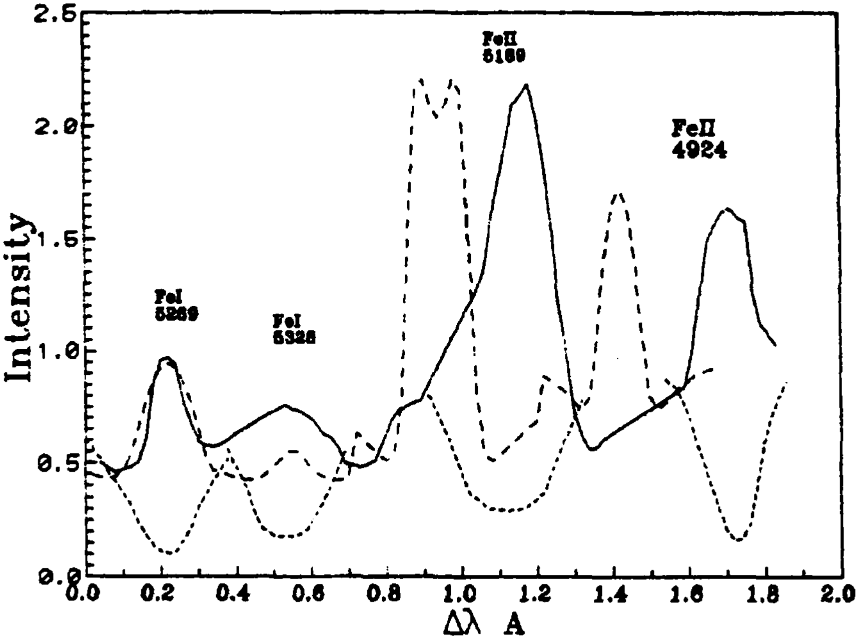

Figure 3 Comparison of the observed (solid line) and calculated (dashed line) profiles of Fe I and Fe II for the importance 3 flare. The undisturbed profiles of lines are presented by dotted line.

and selected were those that gave the best agreement between observed and calculated profiles. It was found that agreement between profiles cannot be achived by changing only the temperature values in the photosphere. The density values N_H also had to be modified. The reason is that the density has an influence on the degree of ionization and so on the ratio of Fe I and Fe II ions. The final models for two solar flares give a satisfactory agreement between observed and calculated profiles for the Balmer lines and the Fe I, Fe II, Ti I and Ti II lines. The resulting models for the photospheric parts of the flares are shown in Figures 1 and 2. A comparison of the observed and calculated profiles for the level 3 flare is shown in Figures 3 and 4 on which the lines from different spectral regions are put pogether with an arbitrary wave length scale. The turbulent velocity was found to be as about 2 km s^{-1} for the region of line formation. For the best agreement of Fe I and Fe II lines profiles a magnetic field of about 1800 gs was used.

3 DISCUSSION

We conclude from our investigation that the emission of Fe I and Fe II lines originates from photospheric levels with optical depths of more than 10^{-4}. The temperature rise in the flare photosphere is not uniform but is located as a hot layer in

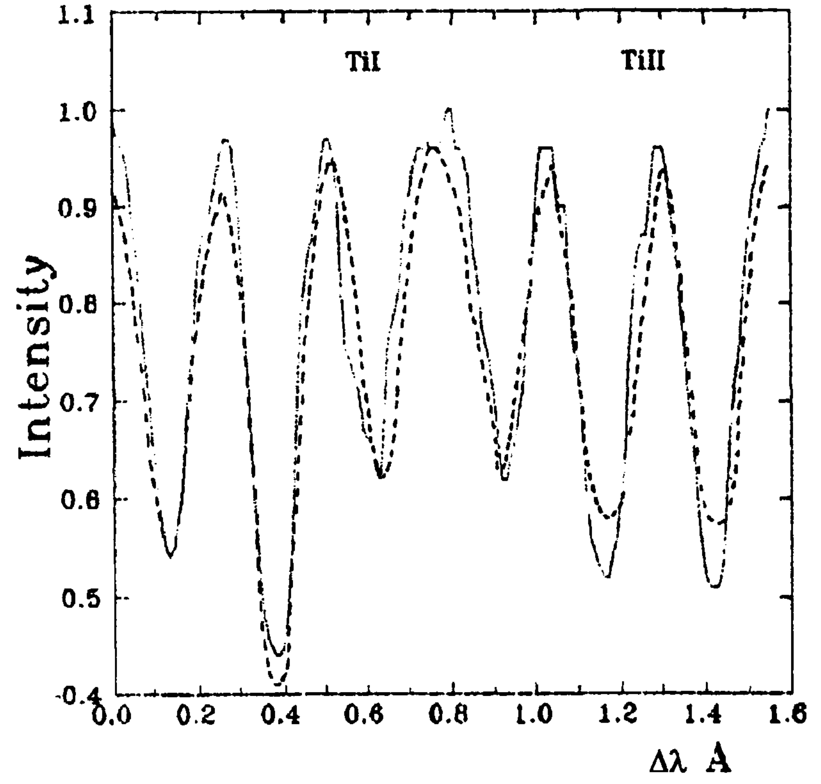

Figure 4 Comparison of the observed (solid line) and calculated (dashed line) profiles of Ti I 5026, 5025, 5145, 5147 Å and Ti II 5337, 5154 Å.

the upper photosphere at optical depth $\tau_{0.5} = 10^{-4}$–10^{-2} as seen in Figure 1. The upper limit of the temperature values in this hot layer is about 7000 K. For higher temperatures the model would give too great an intensity of Balmer continuum.

The density of the importance 2 flare decreases significantly (see curve 2 in Figure 2) and as a consequence the extension of photospheric layers increases up to about 1600 rm. The decrease (or increase) of the density is necessary for simultaneous interpretation of the Fe I and Fe II emission.

4 CONCLUSION

The main results of this investigation are: calculations have shown that the emission of Fe I and Fe II lines in solar flares is formed in photospheric layers at optical depths of 10^{-4}–10^{-2}. The simultaneous interpretation of all considered line profiles is possible only using photospheric models with non-uniform depth dependence of temperature and density.

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