THE EVALUATION OF THE BALMER MERGING EFFECTS IN DIFFERENT CHROMOSPHERIC SOLAR FLARE MODELS

A. Falchi[1], R. Falciani[2], L.A. Smaldone[3], G.P. Tozzi[1]

1 Osservatorio Astrofisico di Arcetri, Firenze, Italy

2 Istituto di Astronomia, Universita' di Firenze, Firenze, Italy

3 Dipartim. Sc. Fisiche, Universita' di Napoli, Napoli, Italy

Abstract

Synthetic spectra computed with semiempirical and theoretical models of the flare atmosphere are discussed. Stark profile of the Balmer lines ($n \geq 6$) and the Balmer continuum have been computed according to Donati-Falchi *et al.* , (1985). A semiempirical model in between the F2 and F3 models proposed by Avrett *et al.* , (1986) might represent a good approximation of the atmosphere of a flare during the impusive phase. Among the theoretical models proposed by Ricchiazzi (1982), the model, indicated as 1073, with very high coronal pressure ($P_0 = 1000\, dyne\, cm^{-2}$) probably represents the best approximation of the emission observed during the impulsive phase of a chromospheric flare. Continuum and Balmer lines ought to be measured and interpreted on the same time for a self-consistent diagnostic of the chromospheric modification.

I. INTRODUCTION

The merging of the highly Stark broadened Balmer lines, close to the Balmer continuum limit, has been already recognized (Donati- Falchi *et al.* , 1985) to be an indicator mainly of the electron density variation in the chromosphere and in the transition region during a flare. Our present interest is to study the influence of the various models of the flare atmosphere on the spectral signatures present in the range between 3600 and 4200 Å, i. e. the Balmer lines higher than H_δ and the Balmer pseudocontinuum near the Balmer discontinuity. Both signatures should be significantly related to the atmospheric modification induced by the flare occurrence.

II. COMPUTATIONAL METHOD

The details of the method used to compute the Stark profile of the Balmer lines ($n \geq 6$) and their merging have been extensively described (Donati- Falchi *et al.* , 1985). In order to compute the absolute continuum emission of a given atmosphere we need to consider the atomic lines "haze" effect, especially important for $\lambda < 4000$ Å. The relative contribution of atomic lines to the total absorption coefficient, as a function of the height in the solar atmosphere, is given for VAL-C model in Vernazza *et al.* , (1976). We assume that the height dependence of the line opacity relative to the total absorption at $\lambda = 4000$ Å is also valid at the other wavelengths. For the wavelength dependence law we assumed a smoothed fit of the line opacity distribution function given in Vernazza *et al.* , (1976, Fig. 3). This wavelength dependence is supposed to be the same

https://doi.org/10.1017/S0252921100154508 Published online by Cambridge University Press

for quiet sun or flare atmosphere. The height dependence of the line opacity contribution cannot be considered the same because of the strong difference in T_e and N_e distribution between the flare and quiet atmosphere. Due to the strong dependence on N_e of the line opacity conribution, it seems reasonable to assume in the flare the same N_e dependence as in the VAL-C atmosphere, neglecting the T_e dependence.

The continuous and the Balmer lines spectrum, calculated with the above described opacity sources for the VAL-C model, satisfactorily fits the absolute disk center intensity measured by Neckel and Labs (1985). This fact makes us confident that our computational procedures are reliable.

III. SEMIEMPIRICAL MODELS

We considered the F1, F2 and F3 chromospheric flare models, proposed by Avrett *et al.* 1986. Those flare models are characterized by the value of the total pressure P_0 in the transition region,which is the boundary condition for the assumed T(m) behaviour. The hydrostatic equilibrium conditions define the corresponding variations of the particle density and the geometrical height scale.

The F1 model is practically invisible in our considered spectral range; only a very small contrast of about 5 % might be observed around 3640 Å. Using the F2 model, both the net absolute emission in the continuum and the shapes of the lines do not match the observed hydrogen spectrum during a flare. As far as the F3 model is concerned, we see (Fig. 1) that the general trend of the synthesized spectrum (both the Balmer pseudo-continuum and the high Balmer line profiles) follows the measurements of some flare spectra (Donati-Falchi *et al.* 1985, Fig. 3 and 4) but the absolute values are roughly one order of magnitude higher than the observed ones. It seems to us that a semiempirical flare model in between F2 and F3 might represent a good approximation of a plane parallel, homogeneous, hydrostatic model of the chromospheric component of the impulsive phase of a solar flare.

IV. THEORETICAL MODELS

Among various existing theoretical models we use the models presented by Ricchiazzi in his thesis (1982) to compute our synthetic hydrogen spectrum. Ricchiazzi carried out a calculation of the chromospheric response to both the non-thermal electrons flux with energy > $20\,Kev$ and the thermal conduction. The effect of the coronal pressure P_0 at the apex of the flare loop is also included. We are grateful to Dr. R. C. Canfield for furnishing the detailed calculation of the hydrogen atom population for each model. We point out that almost all these models have a minimum temperature lower than that of the semiempirical models and that the height dependence of T_e , N_e and the other parameters are strongly affected by the relative importance of the two proposed energy transfer mechanisms and by the value of coronal pressure.

The spectrum of a flare has been computed with models with constant non-thermal electron flux $F_{20} = 10^{10}\,erg\,sec^{-1}\,cm^{-2}$ and with the conductive energy flux F_c varying between 10^6 and $10^8\,erg\,sec^{-1}\,cm^{-2}$. The obtained spectra show a weakening of the Balmer continuum with increasing of conductive flux while the shape of Balmer lines (absorption wings and extremely narrow emission core) does not change. Coronal pressure changes between 1 and 100 $dyne\,cm^{-2}$ do not affect the general behavior of the computed spectrum. This type of spectrum has never been observed and we may conclude that F_c is not a dominant energy transfer mechanism during the impulsive phase of a chromospheric flare, when the Balmer emission spectrum is well detectable.

The flux of the non-thermal electrons is the main heating source in the chromosphere below

https://doi.org/10.1017/S0252921100154508 Published online by Cambridge University Press

the TR and only for high coronal pressure becomes important in the TR too. Flare spectra have been computed for models with $F_c = 10^7\, erg\, sec^{-1}\, cm^{-2}$ and F_{20} values varying between 0 and $10^{11}\, erg\, sec^{-1}\, cm^{-2}$. We point out that a relative increase of the F_{20} importance produces an increase of the Balmer pseudo-continuum emission, with minor effects on the Balmer lines intensities and profiles for coronal pressure $1 \leq P_0 \leq 100\, dyne\, cm^{-2}$. High value of $P_0 = 1000\, dyne\, cm^{-2}$ makes important the heating by non-thermal electrons in the TR too. The net emission of a flare computed for models 1070 and 1073 are shown in Fig. 2-a and -b. We believe that no flare spectra have been observed with shape of Fig. 2-a, while the general shape of the spectrum and the absolute value of the Balmer pseudo-continuum and emission lines of Fig 2-b fit reasonably the measurements of these quantities as quoted in the literature. The model 1073 probably represents the best approximation of the atmosphere of a flare during the impulsive phase . This means that the pseudo-continuum and the Balmer lines higher than H_δ represent an efficient spectral signature of the relative importance of F_{20} relative to F_c.

V. CONCLUSIONS

Taking into consideration the possible relationships between the signatures in this spectral range and the values of physical parameters as N_e and T_e of the various considered models we can conclude that:

- the total intensity and the wing profiles of the high Balmer lines ($n \geq 6$) are sensitive to the values of the maximum electron density above the minimum temperature level;

- the absolute emission of the Balmer pseudo-continuum (3600 - 3700 Å) is strongly sensitive to the value of the electron column density evaluated above the minimum temperature level where $N_e > 10^{13}\, cm^{-3}$;

-the minimum temperature value T_{min} seems to have a negligible effect on the Balmer spectrum.

The Balmer pseudo-continuum , sensitive to the electron column density evaluated above the minimum temperature level, might be a signature of the importance of non-thermal electron flux in the low chromosphere. The Balmer line profiles , sensitive to the maximum value of N_e, might be considered a signature of the coronal pressure value. We stress that for a self-consistent diagnostics of the chromospheric modification produced by a flare both continuum and Balmer lines must be measured and interpreted. The separate consideration of only one spectral signature may yield misleading interpretations.

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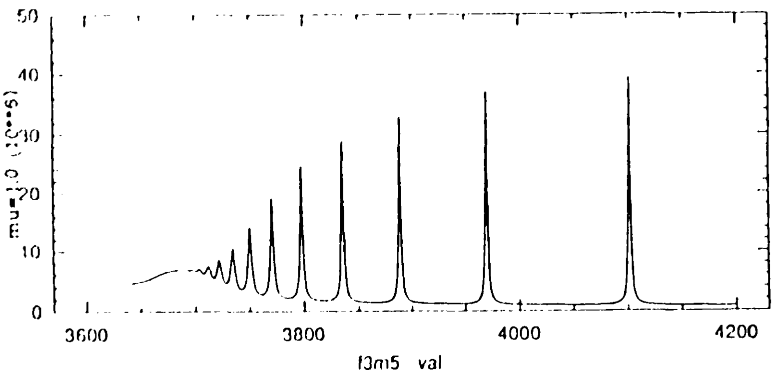

Figure 1 Difference $\Delta I(\lambda)$ between the absolute spectral intensity computed for F3 model and the intensity computed for VAL-C atmosphere at $\mu = 1.0$.

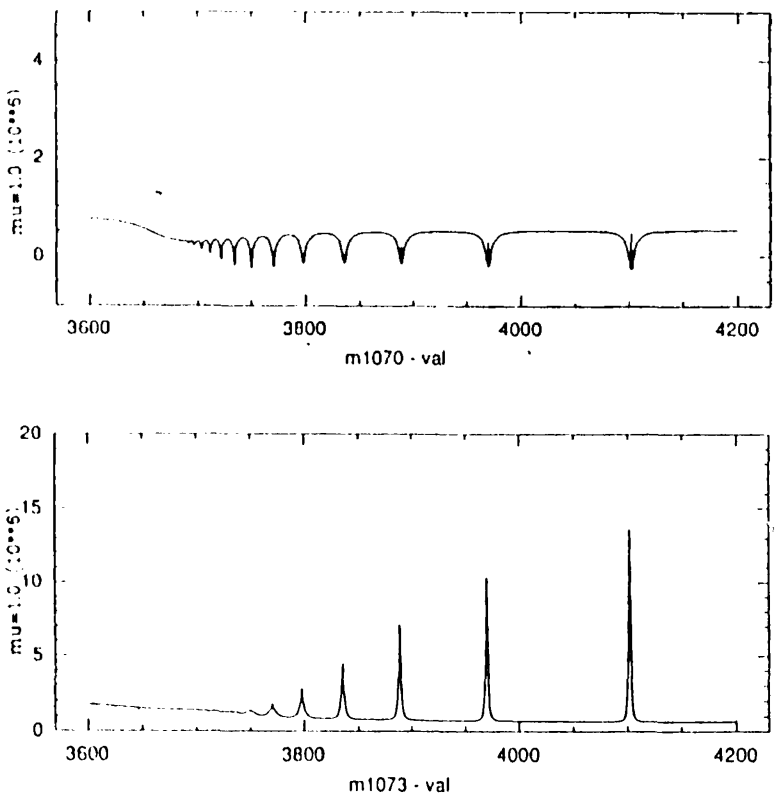

Figure 2 Difference $\Delta I(\lambda)$ between the absolute spectral intensity computed for 1070 and 1073 models and the intensity computed for VAL-C atmosphere at $\mu = 1.0$.

a) 1070 model means : non-thermal electron flux = $10^{10}\, erg\, sec^{-1}\, cm^{-2}$; conductive flux = $10^{7}\, erg\, sec^{-1}\, cm^{-2}$; $P_0 = 1\, dyne\, cm^{-2}$.

b) 1073 model means : non-thermal electron flux = $10^{10}\, erg\, sec^{-1}\, cm^{-2}$; conductive flux = $10^{7}\, erg\, sec^{-1}\, cm^{-2}$; $P_0 = 1000 dyne\, cm^{-2}$.

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