Mem. S.A.It. Suppl. Vol. 19, 117

Memorie della
Supplementi

Solar flares in Hα and Ly-α: observations vs simulations

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Abstract. In order to study the properties of faint, moderate and bright flares, we simulate the conditions of the solar atmosphere using a radiative hydrodynamic model (Allred et al. 2005). A constant beam of non-thermal electrons is injected at the apex of a 1D coronal loop and heating from thermal soft X-ray and UV emission is included. We study the contribution of different processes to the total intensity of different lines at different atmospheric layers. We obtain the total integrated intensity of different lines and we compare those of the Ly-α and Hα lines with the observational values for Ly-α (using TRACE 1216 and 1600 Å data and estimating the "pure" Ly-α emission) and Hα (using data from the Ondřejov Observatory). We inferred from the analysis of the values obtained by simulation that the X-ray energy of the different kind of flares does not strongly affect the Ly-α results; the Hα results are comparable to the observed ones, concluding that the simulated solar atmosphere fits better at lower layers of the chromosphere than at upper layers.

Key words. Sun: activity – Sun: flares

1. Introduction

In order to investigate the process of energy release during solar flares, we simulate the evolution of the solar atmosphere during the impulsive phase of a solar flare and compare the results with the observations.

The NLTE Radyn code models a solar flare in a 1D plane-parallel atmosphere using the plane-parallel equations of radiation hydrodynamics (Carlsson & Stein 1992, 1997).

We obtain the non-LTE solution of the population equations for hydrogen, helium, single ionized calcium and single ionized magnesium atoms, assuming complete redistribution of photons over the line profile. We calculate the evolution of the atmospheric plasma parameters and of selected line intensities as a function of time; we compare the results obtained for the hydrogen atom with the intensity measured in Ly-α and Hα during a solar flare to test agreement between observations and the simulations.

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2. Simulations

A constant beam of non-thermal electrons is injected at the apex of a 1D coronal loop and heating from thermal soft X-ray and UV emission is included (Abbett & Hawley 1999). Cooling resulting from bremsstrahlung and collisionally excited transitions from metals is also added.

The equations are solved on an adaptive grid using 191 grid points in depth, 3 angular points (μ =0.953, 0.500 and 0.231) and up to 100 frequency points for each transition.

We then calculate the radiative-hydrodynamic response of the lower atmosphere at the footpoints of the magnetically confined flare loop, obtaining the variation of the integrated intensity along the Ly-α and Hα profiles for a width of $\Delta\lambda$ = 5 Å.

The non-thermal electron beam is assumed to have a power-law distribution with a spectral index δ =4 and a low-energy cutoff of E_c=20 kev.

During the impulsive phase of the flare, we considered three kinds of flares characterized by a constant and non thermal electron energy flux $\mathcal{F}$.

- $\mathcal{F} = 10^9$ ergs cm^{-2} s^{-1}, hereafter called run F9, which corresponds to *weak* flares. The quiescent atmosphere is heated for 67.1 seconds.
- $\mathcal{F} = 10^{10}$ ergs cm^{-2} s^{-1}, run F10, which simulates *moderate* flares, for a time=45.2 seconds.
- $\mathcal{F} = 10^{11}$ ergs cm^{-2} s^{-1}, run F11, associated to *strong* flares. This case is computationally much more problematic and the run lasts only for 1.62 seconds.

Fig. 1 shows the evolution of the temperature and electron density stratification for the three different flare cases; the dotted line is the initial preflare atmosphere (at t=0 seconds), the red line is the temperature stratification and the blue line is the electron density stratification at each time. Moderate and strong flares have an initial *gentle* phase (see panels (f) and (j)) and a subsequent *explosive* phase (see panels (h) and (l)), characterized by large material flows; Weak flares do not have enough energy to produce the *explosive* phase (Abbett & Hawley 1999).

2.1. Ly-α line

For the Lyman transitions, partial frequency redistribution is mimicked by truncating the profiles at 10 Doppler widths (Milkey & Mihalas 1973). The Ly-α line is strongly sensible to the partial or complete redistributions: the scattering of the Ly-α photons is not isotropic.

Fig. 2 shows the Ly-α light curve during the flare for each run. The variation of the non-thermal electron beam flux ($\mathcal{F}$) weakly affects the Ly-α intensity in time, being only a factor 4 higher for F11 than for F9.

2.2. Hα line

Fig. 3 shows the Hα light curve during the flare for each run. The Hα total integrated intensity shows a different shape in time for each kind of flare, varying by less than a factor of 2 between F09 and F11.

3. Observations

3.1. Ly-α

We studied two different flares using TRACE data: an M1.4 class flare occurred on 08 September 1999 at 12:14:10 UT and an M6.6 class flare occurred on 28 February 1999 at 16:35:58 UT.

We obtained a cleaned version of the Ly-α image by correcting the influence of the 1600 Å TRACE channel on the 1216 Å channel using the formula: $I_{Ly_\alpha} = 0.97 \times I_{1216} - 0.14 \times I_{1600}$(Kim et al. 2006).

Measuring the count rate in a region of 250 × 250 pixels^2 at the footpoints of the flare in the corrected Ly-α image at the beginning of the impulsive phase (using a threshold range between 1200 and 4090 DN), it is possible to estimate the intensity in the flare in Ly-α (Rubio da Costa et al. 2009) (see Table 1).

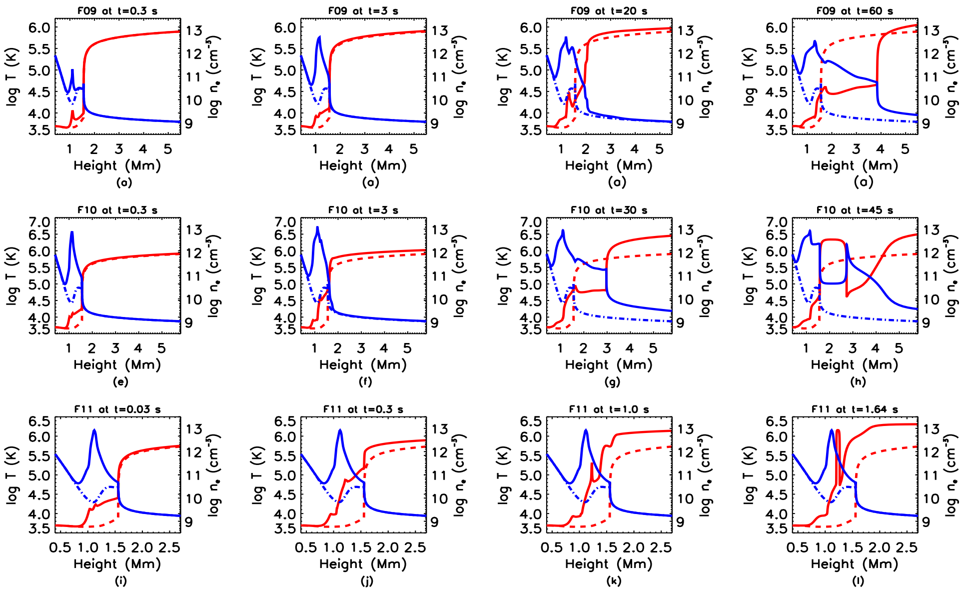

Fig. 1: Evolution of the temperature (red) and electron density (blue) stratification during the F09 (upper pannel), F10 (middle pannel) and F11 (bottom pannel) runs. The dotted line represents the initial preflare atmosphere and the solid line reports the variation of the atmospheric parameters during the simulation.

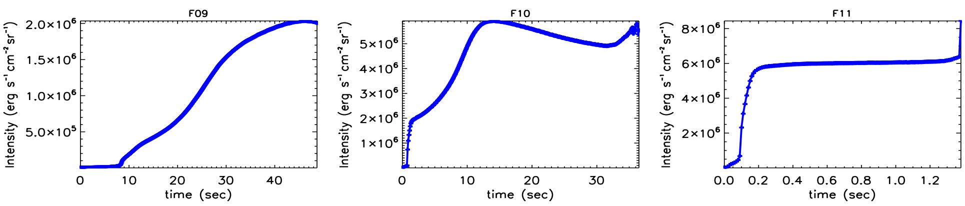

Fig. 2: Ly-α integrated intensity as a function of time for the three different flare models.

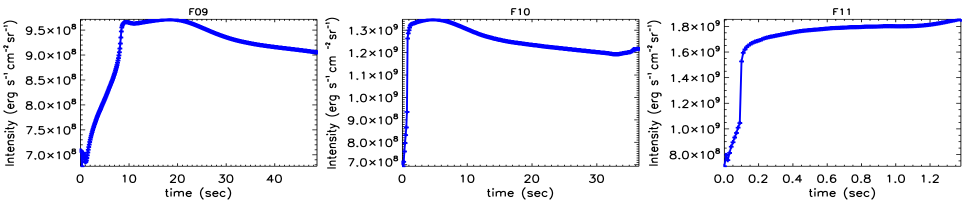

Fig. 3: Hα integrated intensity as a function of time for the three different flare models.

3.2. Hα

A C.3 class flare that occurred on 03 July 2002 at 11:43 UT was observed at the Ondrejov Observatory, with the Multichannel Flare Spectrograph, from 11:56:24 UT to 12:10:42 UT.

We calibrated the data obtaining the intensity at different wavelengths along the Hα line

	M6.6 Flare	M1.4 Flare
I_{1216} (erg s^{-1} cm^{-2} sr^{-1})	1.9×10^6	1.4×10^7
I_{1600} (erg s^{-1} cm^{-2} sr^{-1})	6.2×10^6	3.1×10^6
$I_{L\alpha}$ (erg s^{-1} cm^{-2} sr^{-1})	9.9×10^5	1.4×10^7

Table 1: Intensity estimated at the flare footpoints at the beginning of the impulsive phase for both flares.

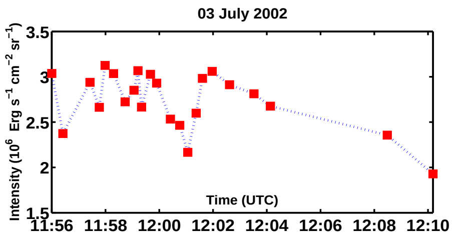

Fig. 4: Hα light curve obtained integrating the intensity along the line profile ($\Delta\lambda = 5$ Å) at different times.

profile at different times determining the evolution of the Hα line profile during the flare integrated within $\Delta\lambda = 5$ Å (see Fig. 4).

4. Conclusions

Comparing the Ly-α value estimated from TRACE images with the theoretical one obtained from the RADYN code for the three different flare models, both are comparable even if the simulated ones are slightly higher: in RADYN, the scattering is assumed to be isotropic and incoherent and the energy flux of the non-thermal electron beam is constant in time. These facts may explain the differences. The integrated intensity in the Hα line obtained from the observations is the same order of magnitude than the simulated ones. The behaviour of the two light curves is different (compare Fig. 3 with Fig. 4): this might be explained by the time variation of the beam flux.

Even if the results from RADYN match the observations, the Hα intensity is better fitted than the Ly-α, concluding that the code fits better the lower chromosphere than the upper layers.

Acknowledgements. Financial support by the European Commission through the SOLAIRE Network (MTRN-CT-2006-035484), STFC rolling grant ST/F002637/1 and Leverhulme grant F00-179A is gratefully acknowledged.

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