CAMBRIDGE JOURNALS

Proof Delivery Form

Proceedings of the International Astronomical Union

Date of delivery: 5 May 2016

Journal and vol/article ref: IAU 1600042

Number of pages (not including this page): 4

This proof is sent to you on behalf of Cambridge University Press. Please check the proofs carefully. Make any corrections necessary on a hardcopy and answer queries on each page of the proofs

Please return the **marked proof** within 5 days of receipt to:

Managing editor of this symposium

Authors are strongly advised to read these proofs thoroughly because any errors missed may appear in the final published paper. This will be your ONLY chance to correct your proof. Once published, either online or in print, no further changes can be made.

To avoid delay from overseas, please send the proof by airmail or courier.

If you have **no corrections** to make, please email **managing editor** to save having to return your paper proof. If corrections are light, you can also send them by email, quoting both page and line number.

- The proof is sent to you for correction of typographical errors only. Revision of the substance of the text is not permitted, unless discussed with the editor of the journal. Only **one** set of corrections are permitted.
- Please answer carefully any author queries.
- Corrections which do NOT follow journal style will not be accepted.
- A new copy of a figure must be provided if correction of anything other than a typographical error introduced by the typesetter is required.

If you do not send any corrections to the editor within 5 days, we will assume your proof is acceptable.

- If you have problems with the file please contact **lwebb@cambridge.org**

Please note that this pdf is for proof checking purposes only. It should not be distributed to third parties and may not represent the final published version.

Important: you must return any forms included with your proof. We cannot publish your article if you have not returned your signed copyright form.

NOTE - for further information about **Journals Production** please consult our **FAQs** at http://journals.cambridge.org/production_faqs

Author queries:

Typesetter queries:

Non-printed material:

Solar and Stellar Flares and their Effects on Planets
Proceedings IAU Symposium No. 320, 2015
A.G. Kosovichev, S.L. Hawley & P. Heinzel, eds.

doi:10.1017/S1743921316000429

Response of Chromospheric Lines to Different Periodic Non-thermal Electron Beams

Jianxia Cheng[1,2] and Mingde Ding[3]

[1]Key Laboratory of Planetary Sciences, Shanghai Astronomical Observatory, Shanghai 200030, China
email: `chengjx@shao.ac.cn`

[2] Key Laboratory of Solar Activity, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China

[3]School of Astronomy & Space Science, Nanjing University, Nanjing 210093, China
email: `dmd@nju.edu.cn`

Abstract. Solar flares produce radiations in very broad wavelengths. Spectra can supply us abundant information about the local plasma, such as temperature, density, mass motion and so on. Strong chromospheric lines, like the most studied Hα and Ca II 8542 Å lines are formed under conditions of departures from local thermodynamic equilibrium in the lower atmosphere subject to flare heating. Understanding how these lines are formed is very useful for us to correctly interpret the observations. In this paper, we try to figure out the response of chromospheric lines heated by different periodic non-thermal electron beams. Our results are based on radiative hydrodynamic simulations. We vary the periods of electron beam injection from 1.25 s to 20 s. We compare the response times to different heating parameters. Possible explanations are discussed.

Keywords. solar flare, radiative transfer, numerical simulation

1. Introduction

It has been known for many years that solar flares may exhibit fast fluctuations in emissions at various wavelengths. Early studies were focused on radio and hard X-ray observations. Fluctuations in optical lines have also been studied using ground instruments (e.g. Wang *et al.* 2000). Such fluctuations can be attributed to small-scale magnetic reconnections in the corona. High-energy electrons are recognized to be responsible for the hard X-ray and microwave emissions. Kašparová *et al.* (2009) studied the effect of short-duration electron-beam pulses on the temporal evolution of hydrogen Balmer lines using the *Flarix* code. Different from hard X-rays, optical lines take a little more time to respond to the impulsive beam heating. Trottet *et al.* (2000) compared the Hα time profile with the hard X-ray emission. Their result indicates that the chromospheric part of the flare is subject to heating by nonthermal electrons. Wang *et al.* (2000) found high frequency fluctuations in Hα wing at the footpoint which is spatially correlated with the hard X-ray source. Ding *et al.* (2001) performed numerical calculations to explain the fast variations of the Hα wing emission. In this paper, we study the response of chromospheric lines from an atmosphere heated by different periodic nonthermal electron beams using radiative hydrodynamic simulations.

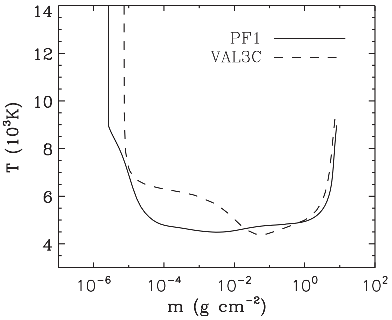
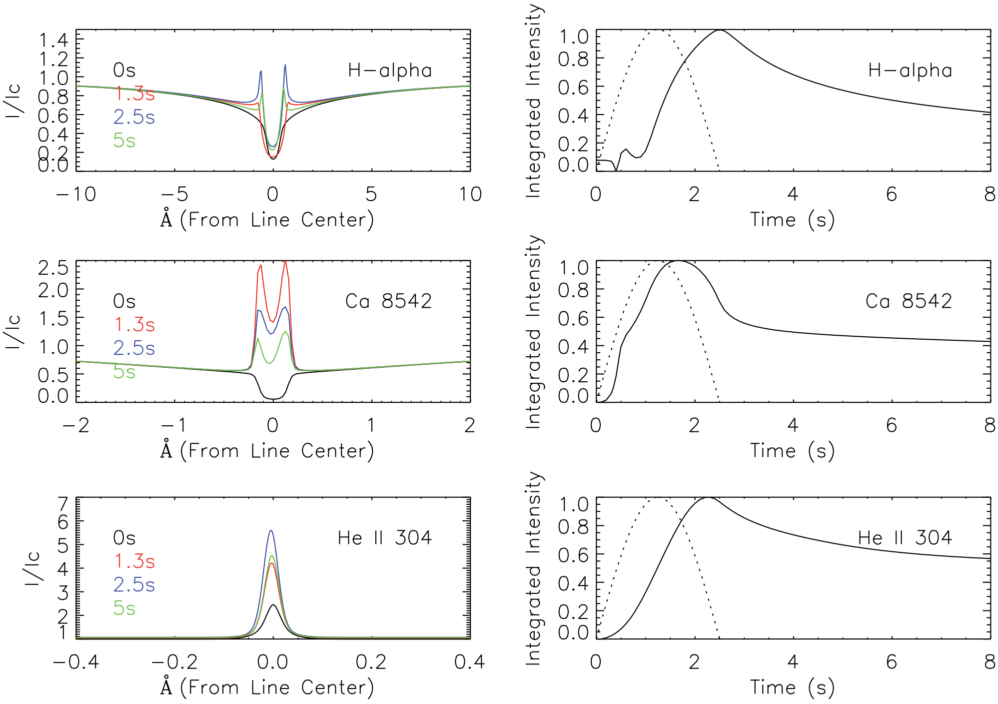


Figure 1. The base model, the PF1 model, adopted in the simulations. The VAL3C model is displayed for comparison.

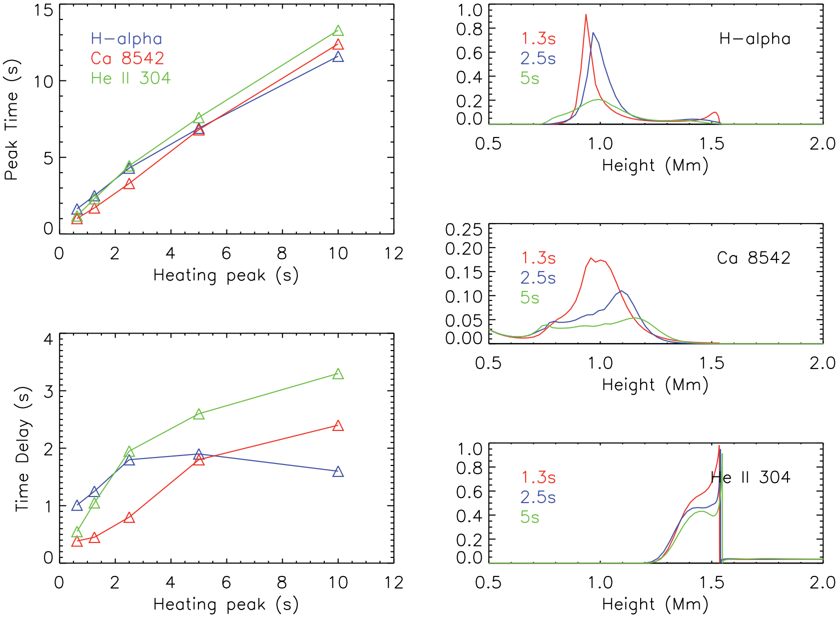


(a) (b)

Figure 2. (a) Line profiles of three lines, Hα, Ca 8542 and He 304 Å from an atmosphere heated by an electron beam. Here, $\alpha = 5$ s. (b) Normalized integrated intensities varying with time. Here, $\alpha = 5$ s. The dashed lines refer to the electron beam flux.

2. Numerical Method

We perform radiative hydrodynamics modeling using the code RADYN with application to solar flares as described in detail in Abbett & Hawley (1999). The simulations are started with the PF1 initial atmospheric model (Figure 1). The atmosphere is heated by a non-thermal electron beam which is assumed to have a power-law distribution with a spectral index $\delta = 4$ and low energy cutoff $E_c = 40$ keV. The electron flux is assumed to vary sinusoidally with time as $F(t){=}F_0\sin(2\pi t/\alpha)$, where $F_0 = 10^{10}$ ergs cm^{-2} s^{-1}, and



(a) (b)

Figure 3. (a) Peaking times and time delays of integrated intensities varying with different heating peaks ($\alpha/4$). (b) Contribution functions at line wings varying with height. Here, $\alpha = 5$ s.

$\alpha = 2.5$ s, 5 s, 10 s, 20 s, and 40 s. The electron beam heating lasts for a time period of $\alpha/2$.

3. Computations and Results

Here, we take the case of $\alpha = 5$ s as an example to show the spectral line evolutions in three different lines (Figure 2a). As the non-thermal heating continues, the intensities at all the three wavelengths show some enhancements. For the Hα line, the intensity shows a slight decrease at the line center firstly, and then starts to increase. A central reversal occurs at the same time. The He II 304 Å line shows a very significant enhancement during the non-thermal heating. In general, all the three lines show some enhancements when the atmosphere is heated by non-thermal electrons although their peak times and variations show some differences. Furthermore, we compare the integrated intensities with the non-thermal electron fluxes directly (Figure 2b). Time delays between the peak of integrated intensity and the heating rate peak are very obvious. Based on the calculations above, we vary the heating duration as $\alpha/2 = 1.25$ s, 2.5 s, 5 s, 10 s, 20 s to check how these lines respond to this parameter. The results are displayed in Figure 3a. It is seen that the peak times of integrated intensity are correlated well with those of the non-thermal heating rate. The bottom panel of Figure 3a shows the time delays of the line intensity peak relative to the heating rate peak. As the heating duration increases, the time delays become larger in most cases; the only exception is the Hα line, for which the time delays decrease when the heating duration lasts for 10 seconds ($\alpha = 20$ s). The different responses of the three lines may be partly attributed to their different formation regions. Note that the peak time of the He II 304 Å line is somewhat later than that of the Ca II 8542 Å line in this case. Probably this is due to a relatively high low energy cutoff of the electron beam adopted here, which tends to deposit energy at a relatively lower height. The intensity contribution functions at line wins varying with heights are given in Figure 3b. Here, the heating parameter $\alpha = 5$ s. As the electron beam heating continues, distributions of the contribution functions vary slightly. In fact, the line formation regions are very complicated because of the complexity in the atomic transition processes which are seriously affected by the local atmospheric conditions. Line center and wings should be formed in different atmospheric layers.

Acknowledgements

This work is supported by NSFC under grants 11303073 ,11373023,11133004, 11103008, and the strategic priority research program of the Chinese Academy of Sciences (Grant No. XDB09000000). This research is also supported by the open project of Key Laboratory of Solar Activity, National Astronomical Observatories, Chinese Academy of Sciences.

References

Abbett, W. P. & Hawley, S. L. 1999, *ApJ*, 521, 906

Ding, M. D., Qiu, J., Wang, H., & Goode, P. R. 2001, *ApJ*, 552,340

Kašparová, J., Varady, M., Heinzel, P., Karlicky, M., & Moravec, Z. 2009, *A&A*, 499, 923

Trottet, G., *et al.* 2000, *A&A*, 356, 1067

Wang, H., Qiu, J., Denker, C., Spirock, T., Chen, H., & Goode, P. R. 2000, *ApJ*, 542, 1080