Boletim da Sociedade Astronômica Brasileira, **36**, no. 1, 80-81

Simulation and analysis of the Hydrogen Balmer series in solar flares

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Abstract. We simulate the high-order Balmer spectrum hydrogen emission, using radiative-hydrodynamic computational (RHD) modeling of the dynamics of the atmosphere and line formation, starting from its eighth transition line (H8) up to its high order transition of the series. We employed the database of F-CHROMA RHD models which describes the evolution of the solar atmosphere during solar flares subjected to different energy deposition scenarios. The synthetic Balmer spectra was obtained from the Lightweaver framework, considering a H atom model with 21 energy levels. We present the analysis of the solar atmosphere behavior when subjected to different energy injections, and we compare the lines asymmetries and intensities of the Balmer lines as a function of the energy deposition parameters.

Resumo. Nós simulamos o espectro de emissão de alta ordem da série de Balmer do hidrogênio, usando simulações computacionais radiativo hidrodinâmicas (RHD) como forma de modelar a dinâmica presente na atmosfera solar e a formação das linhas espectrais, iniciando pela oitava linhas de transição (H8) e adiante para as linhas de transição da alta ordem da serie. Nós empregamos os modelos RHD presentes na base de dados F-CHROMA, os quais descrevem a evolução da atmosfera do Sol durante explosões solares quando a mesma é submetida a diferentes cenários de deposição de energia. O espectro de Balmer foi sintetizado a partir da ferramenta Lightweaver, a qual utiliza o modelo do átomo de hidrogênio com 21 níveis de energia. Nós apresentamos aqui a análise do comportamento da atmosfera solar quando submetida a diferentes injeções de energia e comparamos a a assimetria e intensidade seus perfis em função dos três principais parâmetros de deposição de energia.

Keywords. solar flares – spectroscopy – Balmer series

1. Solar Atmosphere response

Every model consists of a different scenario of energy deposition (Carlsson et al 2023). We selected only the 79 available models and calculate which was the total energy present in every one of then. We highlighted that every model of the database has the energy transport made by the theory of energy injection using a beam of accelerated coronal electrons, and presents a Fokker-Plank kinetic theory (Allred et al 2020). The atmosphere response was obtained by using the module rapynpy. We took the model with the highest total energy, Figure 1 and the one with the lowest to compare the atmosphere response. We observe chromosphere compression in both models due to energy injection, observed in temperature (T), increase in beam heating (Q), electron (n_e) and proton density (n_q) for the model with high energy, and negative plasma velocity (v) that indicates downward plasma movement for both models.

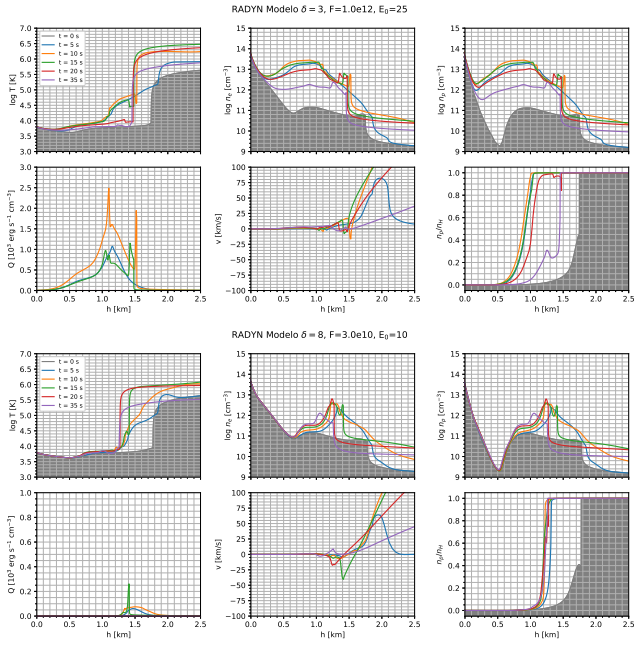

Figure 1. Solar atmosphere response for different energy injection. Top: Highest energy electron beam model. Bottom: Lowest energy electron beam model.

2. Balmer spectrum

By using the Lightweaver framework (Osborne et al 2021), we obtain the Balmer spectra for each Model. It reveals how the spectral lines evolved during the energy injection Figure 2. Is was possible by the use of Radiative-hydrodynamic simulations (RHD), which has been used in the last decades for model the solar atmosphere dynamic during the flare events (Allred et al 2015) .The model with the highest total energy presented all of his lines in emission, i.e values above $2\times10^{-8}\ Wm^{-2}Hz^{-1}ster^{-1}$, being t=10 s, i.e instant of peak of energy deposition, the instant with high emissions. As expected, the lines intensity is proportional to the energy deposition.

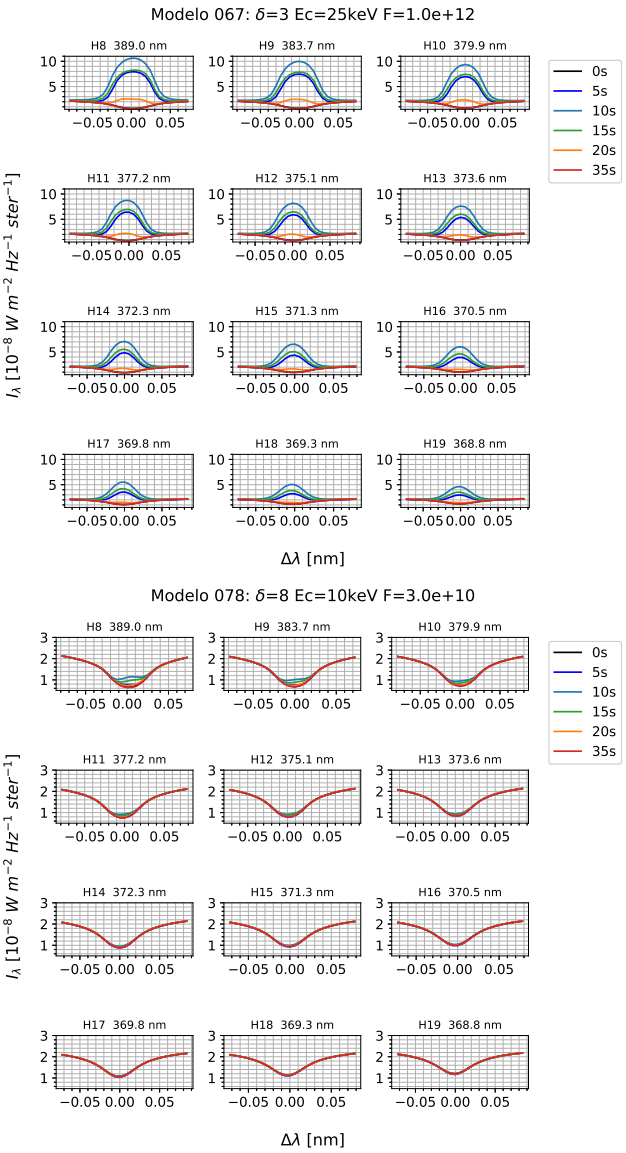

Figure 2. Balmer lines evolution of the models. Top: Highest energy model. Bottom: Lowest energy model.

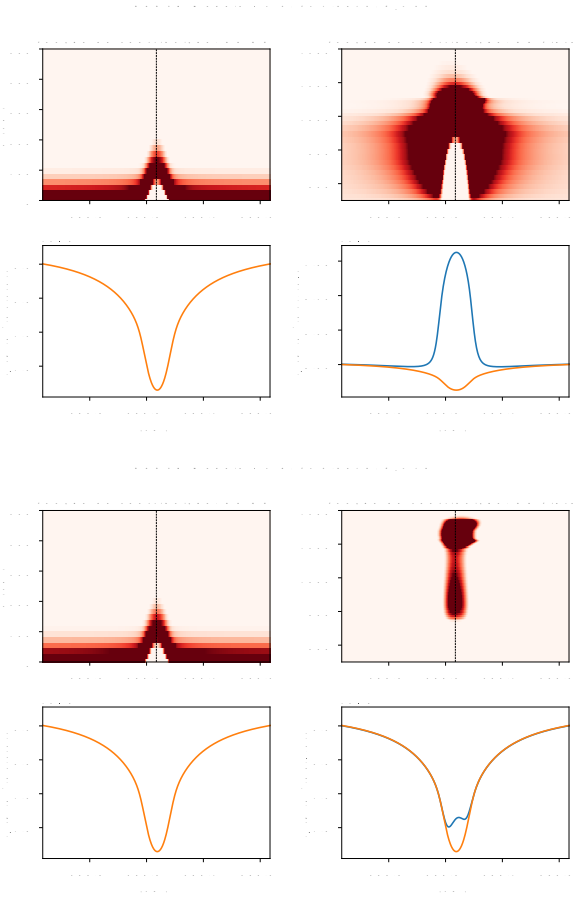

Figure 3. Contribution function of the H8 line. Top: Highest energy model. Bottom: Lowest energy model.

3. Contributing regions

This analysis showed how each region contributes for the emission, as well as the wavelength deflection from the line value. We compute the most intense line (H8), see Figure 3, for quiet Sun and flare condition and found that high energy deposition in flares are associated with larger regions of contribution and wavelength deviations that surpasses 0.1 nm.

Acknowledgements. GFSS acknowledges support from CAPES. The authors acknowledge the partial financial support received from FAPESP grants 2018/04055-8 and 2022/15700-7, CNPq grant 150817/2022-3, as well as MackPesquisa funding agency from Universidade Presbiteriana Mackenzie. PJAS acknowledges support from CNPq grants 307612/2019-8 and 305808/2022-2.

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