Suppression of Hydrogen Emission in a White-light Solar Flare

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Suppression of Hydrogen Emission in a White-light Solar Flare

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Abstract

We present an analysis of an X-class flare that occurred on 11 June 2014 in active region NOAA 12087 using a newly developed high cadence Image Selector operated by Astronomical Institute in Ondrejov, Czech Republic. This instrument provides spectra in the 350 - 440 nm wavelength range, which covers the higher order Balmer lines as well as the Balmer jump at 364 nm. However, no detectable increase in these emissions were detected during the flare, and support observations from SDO/EVE MEGS-B also show that the Lyman line series and recombination continuum were also suppressed, particularly when compared to an M-class flare that occurred an hour earlier, and two other X-class flares on the preceding day. The X-class flare under investigation also showed strong white light emission in SDO/HMI data, as well as an extremely hard electron spectrum ($\delta \approx 3.6$), and γ-ray emission, from RHESSI data. This unique combination of datasets allows us to conclude that the white light emission from this flare corresponds to a black body heated by high-energy electrons (and/or ions), as opposed to optical chromospheric emission from hydrogen.

Introduction

About 40 years ago Machado & Rust (1974) observed a white-light flare using a slit spectrograph working in waverange 350 - 430 nm and detected strong emission in higher order Balmer lines, calcium lines, and increased continuum of up to 12% around Balmer jump. Machado et al. (1986) then concluded that two types of white-light flares (WLF) are distinguished and each one can be a mixture of both types. Type I was described as flares with strong and broad Balmer lines caused by f-b transitions and originating in chromosphere at a temperature about 10^4 K, in contrast with type II with much weaker Balmer lines and flat wavelength dependence originating deeper in photosphere with density higher than 10^{15} cm^{-3} and strong H$^-$ contribution. An observation close to the limb was reported by Boyer et al. (1985). The measured contrast around Balmer jump reached up to 19 % and emission in CaK, CaH and Hϵ lines were detected. Authors concluded that Paschen or H$^-$ continuum were unlikely responsible for the detected emission. Instead they proposed a presence of a slightly ($\approx$ 150 K) warmer layer in the photosphere while speculating about an existence of this phenomena in the absence of a flare just due to an evolution of magnetic structures within active regions.

Kowalski et al. (2015) studied a response of dMe class stars' atmosphere on high energy electron fluxes using RADYN code and compared it with observations. They concluded that high flux (10^{13} erg cm^{-2} s^{-1}) of non-thermal electrons produce a heated, high-density chromospheric condensation layer with a high hydrogen b-f and f-f opacity. In their simulations this atmosphere then produce black-body radiation with a temperature around 10^4 K and a relatively small Balmer jump ratio.

Target

On 11 June 2014 an X-class flare was observed in an active region 12087 on the eastern limb of solar disc (position S18E57). This flare was the forth strong event in this active region detected in last 24 hours. On 10 June two events were classified by the *Geostationary Operational Environmental Satellites* (GOES) as X2.2 and X1.5. The following day M3.0 and X1.0 events occurred.

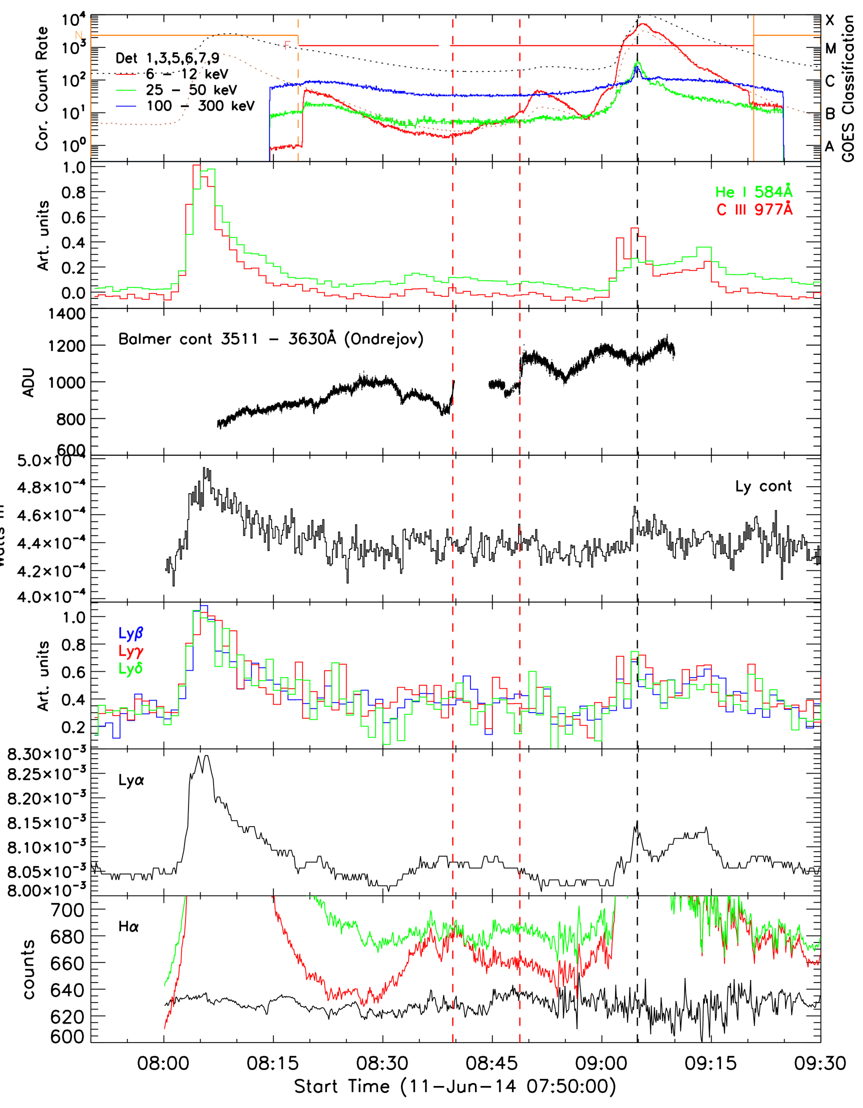


Figure 1: Light curves of both M3.0 and X1.0 class events. Red vertical dashed lines mark two brightenings seen in Balmer continuum, black dashed line marks a presence of high-energy particle beams.

Main Findings

1. Absence of higher order Balmer and Lyman lines.
2. White-light emission.
3. Two sudden brightenings in Balmer continuum channel (351 - 365 nm).
4. Very hard particle beams, including ions.

Analysis

Spectroscopic observations

To explain an origin of white-light flares their spectrum is crucial to obtain. However due to a strong background radiation in visible range, contrast of the flare on the solar disk is too low to measure an irradiance from the whole disc.

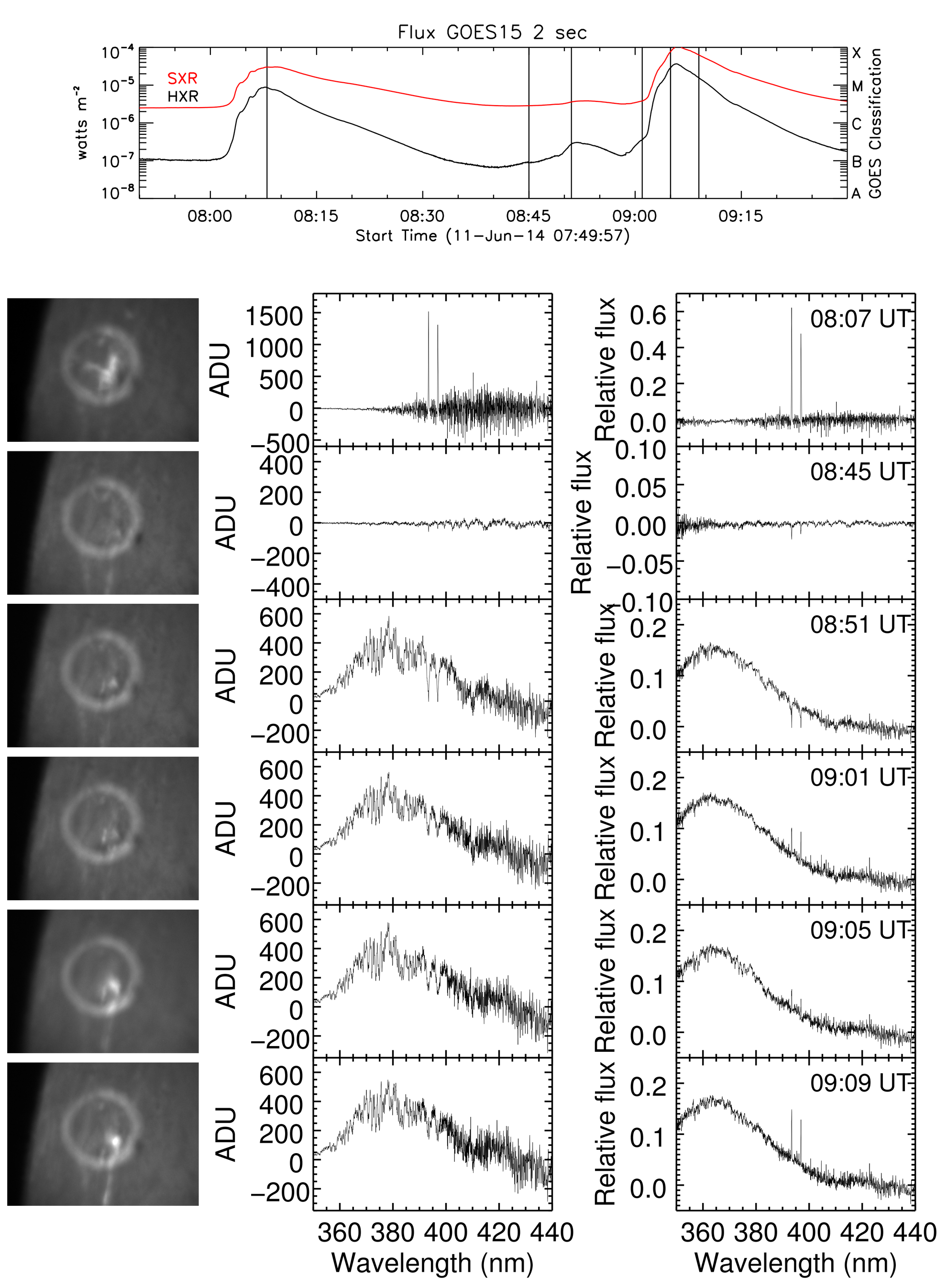


Figure 2: Spectral observations of M3.0 and X1.0 class flares. Vertical lines in the upper panel mark times when the underlying spectra were acquired. Left column shows context Hα image, the middle column a signal excess (QS spectrum is subtracted), in the right column signal from the middle column is divided by quiet solar spectrum.

Image Selector together with 1D spectrometer provide high cadence spectra in waverange 350-440 nm with average spectral resolution 27 pixels nm^{-1} - Kotrč et al. (2016). The device is equipped with Hα context camera showing solar chromosphere and a bright circle. Only area inside of the circle is measured by the instrument. Six snapshots of different stages of the flare are shown in Figure 2, first shows the M3 class event, the second was taken to provide a comparison with a quiet Sun. Absence of Balmer lines agrees with observations of SDO/EVE (left panel in Figure 3), that show suppressed emission in Lyman lines in the X1 event. In contradiction with that, Figure 4 shows very strong emissions in higher order Balmer lines during X2.2 and X1.5 flares. Both X-class events show an increase in Balmer continuum emission (<400 nm) of up to 20 %.

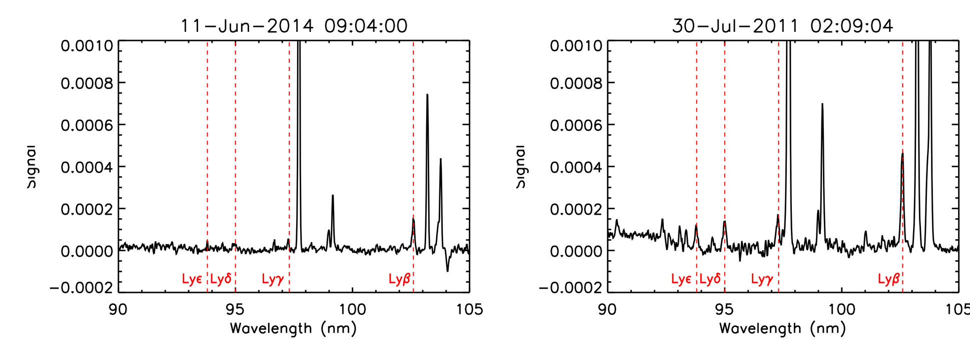
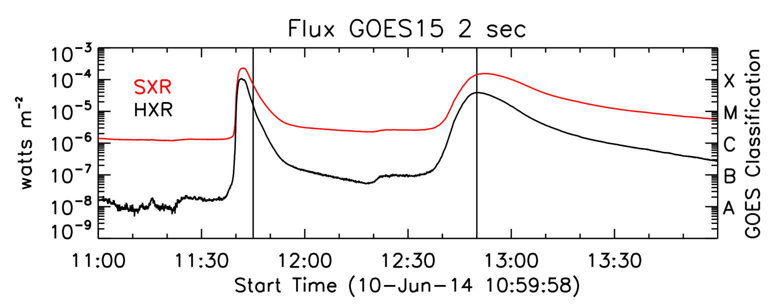


Figure 3: Comparison of two flaring difference spectra from SDO/EVE showing two X-class events. Left plot shows an absence or strong suppression of Lyman lines compared to an 'ordinary' X-class flare in the right plot.



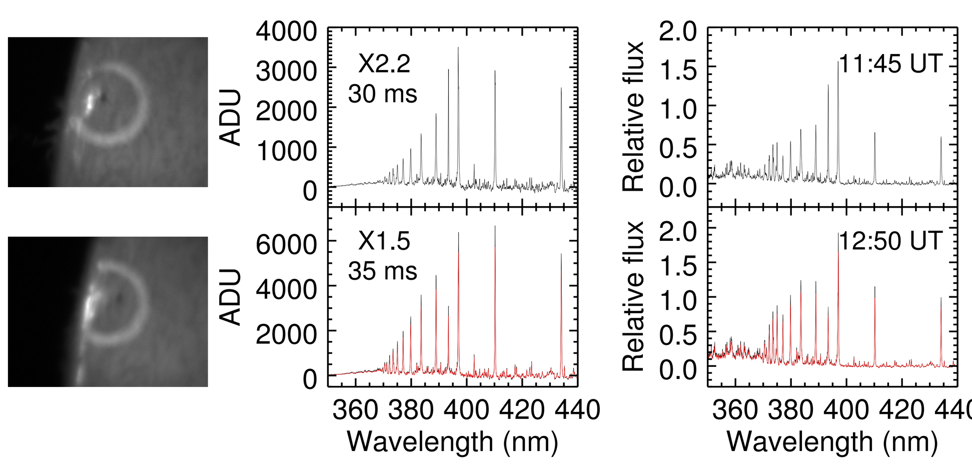


Figure 4: Observations of X2.2 and X1.5 flares on 10 June 2014 with emissions in Balmer lines. Red spectrum was rescaled to match the first observation.

Satellite data

SDO/HMI observations show WL emissions during all studied flares. M3 event shows several bright points, some of them lasting several dozens of minutes, X1 event produced a ribbon-like structure during the impulsive phase and a long lasting bright point in the decay phase. Yellow light curve in the bottom panel of Figure 5 shows a decay phase of a bright spot lasting about one hour, the green light curve shows gradual increase exceeding the investigated time range. These lifespans are significantly longer that those seen with TRACE or Swedish Solar Telescope. Brief analysis of RHESSI observation shows a presence of very hard particle beams. Spectral index during the impulsive phase probably reached value of 3.6. Observations do not match proposed scenario of type I nor type II WL flares, as both produce b-b hydrogen emission.

Hα evolution

Observations in Hα line of Kanzelhöhe Obs. show two bright kernels going to emission at 8:30 UT. Second peak at 8:39 UT matches with Balmer continuum brightening, but no X-rays were detected. Another Hα emission starts at 8:45 UT, but its origin is unclear as it can be seen in all three Hα boxes. Four minutes afterward a 15 % increase in Balmer continuum was detected followed by a SXR burst.

SXR, Balmer cont. and Hα then show the same trends. Just before the impulsive phase, Hα shows a dip lasting nearly 2 minutes and reaching 4 - 5 % of the quiet flux. Bottom panel of Figure 1 shows three light curves coming from three different boxes over those a mean value was calculated. The red one comes from a box focused on the flaring kernels, meanwhile the green one includes a plage region and best matches the area measured by Image Selector. Black light curve shows the quiet Sun.

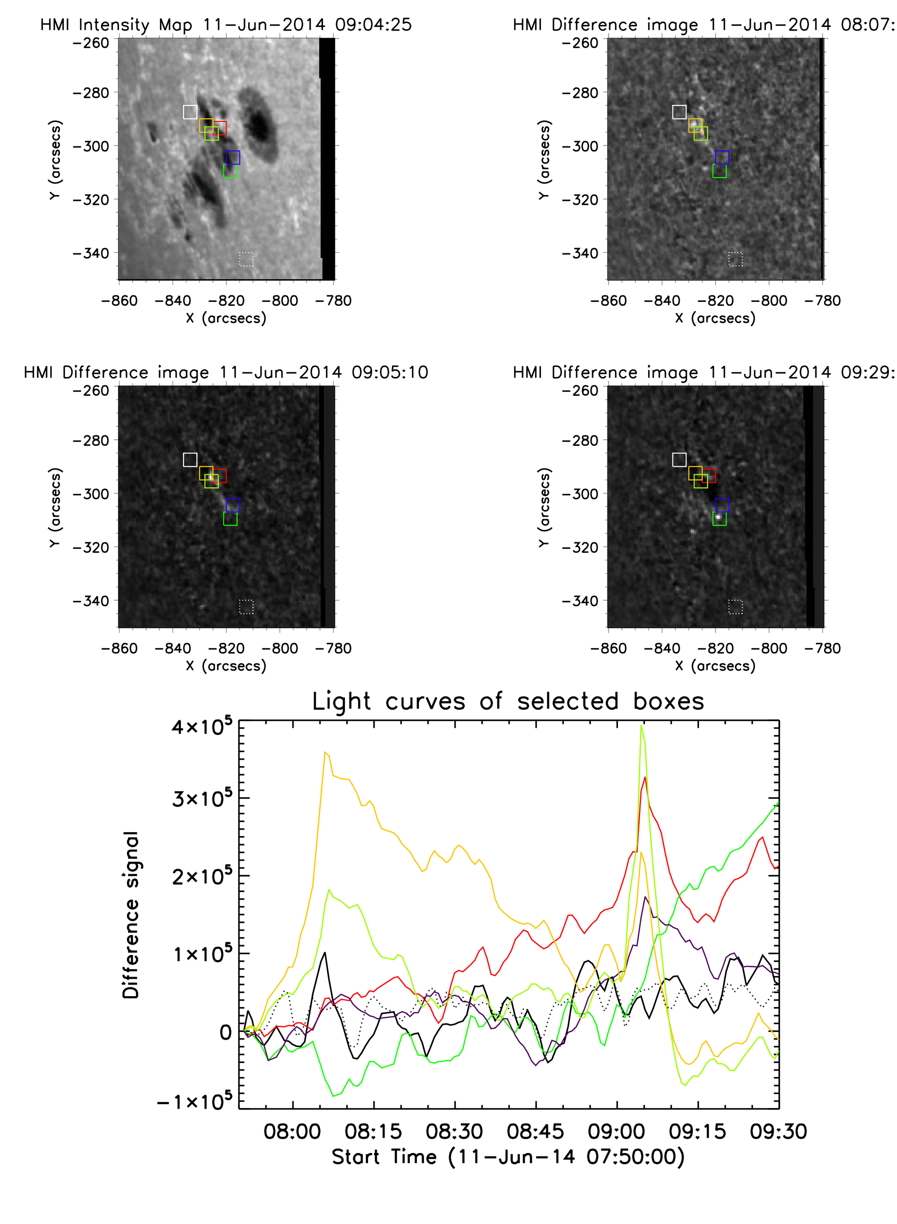


Figure 5: White-light emission as recorded by SDO/HMI. Difference images show several bright spots and faint ribbon-like structures during both M3 and X1 class flares. The lifetime of bright spots vary from several minutes (one peaking at 9:05 UT) up to an hour. The lifetime of ribbon-like structures is harder to estimate, but seem to correlate with hard particle beams.

Conclusions

A suppression of hydrogen lines along with increased flux in wavelengths < 400 nm during a white-light emission might suggest that this emission is rather coming from a hot black-body component as proposed by Kowalski et al. (2015).

Forthcoming Research

To explain the origin of WL flares shown in this poster, analysis of optical depth might be performed. HMI data are suitable for a technique proposed by Potts et al. (2010), who studied photospheric variations and their visibility through the ribbon.

Also lots of theoretical work has to be done, such as hydrodynamics modeling using RADYN or RH code.

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