Title:

Balmer jump spectra of solar flares

Mentors:

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Background:

The white-light continuum emission spanning the NUV, optical, and IR wavelengths constitutes the majority of the energy released in solar and stellar flares. In solar flares, the white-light is cotemporal and cospatial with the hard X-ray bremsstrahlung emission from nonthermal electrons and thus the white-light is thought to result from the atmospheric heating by accelerated electrons. The Balmer jump spectral region (350-450 nm) includes important diagnostics and constraints on the charge density and optical depth in the continuum-emitting layers; these spectra can be directly compared to new, state-of-the-art radiative-hydrodynamic flare models.

However, few current instrumental setups provide broad wavelength coverage and blue sensitivity for such spectra during solar flares. The current constraints on flare models of the atmospheric response to electron beam heating, or other types of flare heating, are instead limited to poorly suited observations in the wing of an Fe I line (e.g., with SDO/HMI), a very narrow continuum region in the NUV (with IRIS), or to the few spectra covering the Balmer jump region that were obtained in the early 1980s. It is well known that these spectra did not systematically sample the brightest kernels in solar flares, or it was ambiguous whether the slit fell on the most interesting region of the flare due to the lack of adaptive optics and high spatial resolution context images. Now, we have advanced adaptive optics and high spatial resolution capabilities; moreover, RHESSI and Fermi provide detailed constraints on the nonthermal hard X-ray spectrum (and indirectly, the parameters of nonthermal electrons).

In Figure 1, we show a flare spectrum from the Universal Spectrograph during an X-class flare, compared to a spectrum covering a larger wavelength region during a flare from an M dwarf [1]. Qualitatively, the spectra are similar with bright continuum emission at $\lambda \lesssim 370$ nm (and also bright, blue continuum at $\lambda > 400$ nm in the M dwarf case) and bright Balmer lines in emission. The ratio of continuum flux at $\lambda < 370$ nm to the ratio of continuum flux at $\lambda > 400$ nm is the “Balmer jump ratio” which gives the optical depth in the continuum emitting layers. The amount of blending of the Balmer emission lines at $\lambda = 360$-400 nm is proportional to the ambient flare electron and proton density in the line-emitting regions.

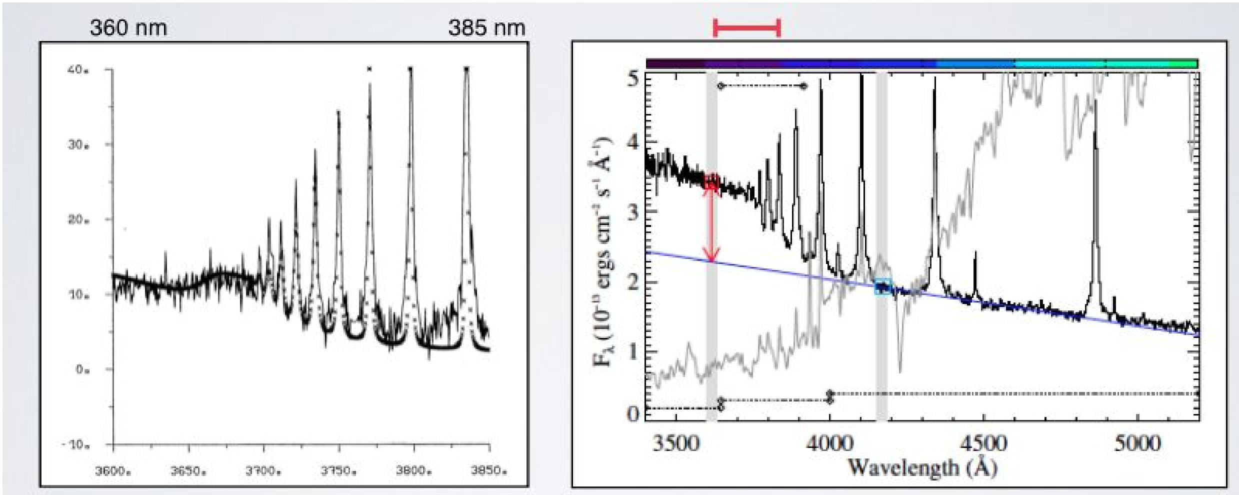

Figure 1 -- (Left) Spectrum of a solar flare from Donati-Falchi et al. (1985 A&A 152, 165). The solid black line is a model. (Right) -- Spectrum of a flare from the active M dwarf AD Leo from [1]. The black spectra is the flare, and the gray spectrum shows the flux from the rest of the (non-flaring) star. The wavelength range for the solar flare spectrum is shown as a red bar at the top. Hydrogen Balmer lines are in emission and the continuum flux becomes very bright at **λ**<400 nm in both spectra. We would like to make quantitative comparisons over the same wavelength region with new solar flare spectra to compare to the spectra on the right.

It has not yet been resolved whether the source of the WL emission in solar flares is primarily in the upper chromosphere over low optical depth, in the upper chromosphere over high optical depth, in the upper photosphere (over high optical depth), or whether there is a combination of chromospheric and photospheric sources that varies from flare to flare. Furthermore, the source of the nonthermal electrons is currently controversial [2], and understanding the origin of WL emission can improve our understanding of particle acceleration in solar flares.

Project description:

The PI has purchased a spectrometer-in-a-box (grating, collimator, camera; Figure 2) to determine the Balmer jump ratio and hydrogen line characteristics in solar flares using the Dunn Solar Telescope. The spectrometer (R~20,000) has high NUV sensitivity in the spectral range from 320 nm - 550 nm with exposure times as short as 1 ms. A 200 micron fiber attached to the spectrometer will cover a diameter of 10-60 arcseconds on the Sun. We follow the strategy of a group at the Ondrejov observatory, who has used a similar spectrometer to successfully obtain Balmer jump spectra during three X-class flares [3]. However, these observations missed the impulsive phase and were not intensity-calibrated, which precludes a direct comparison to models.

Figure 2 -- The Avantes ULS2048L spectrometer-in-a-box.

The Sun is still producing occasional small flares this Solar Cycle, and we will seek to obtain intensity-calibrated spectra of an active region during a flare. The Balmer jump ratio (χ) will determine if the continuum originates over low optical depth (χ~10) or large optical depth (χ~1.5-3). We will compare these quantities to new radiative-hydrodynamic predictions from the RADYN and RH codes. The observations will provide the first direct comparison to spatially unresolved flare spectra of other stars (e.g., Figure 1 right) that produce a bright continuum component that is well-represented by a T~10^4 K blackbody-like continuum. We have proposed for an engineering run in January 2017 to setup the instrument, determine the optimal fiber size on the Sun, and obtain test observations (and hopefully some flares!).

If no significant flares are observed, active region monitoring of the chromospheric lines will be useful for understanding quiescent magnetic activity of other stars and the influence on planet detections. We have also proposed to simultaneously run IBIS Hα observations to characterize the high spatial resolution development of the flare ribbons within the fiber field of view (such as those in [4]).

Papers:

[1] Kowalski, A. F. et al. 2013, *Astrophysical Journal Supplement Series* 207, 15.

[2] Fletcher, L. & Hudson, H. S. 2008, *Astrophysical Journal* 675, 1645.

[3] Kotrc, P. et al. 2016, *Solar Physics* 291, 779.

[4] Kowalski, A. F. et al. 2015, *Astrophysical Journal* 798, 107.