Spectral Irradiance Variability in Lyman-Alpha Emission During Solar Flares

Luke H. Majury[1], Ryan O. Milligan[1], Elizabeth C. Butler[1], Harry J. Greatorex[1]
[1]Astrophysics Research Centre, Queen's University Belfast

INTRODUCTION:

The Hydrogen Lyman-alpha line (Lyα;1216Å) is the brightest emission line in the quiescent solar spectrum. The line wings and core form at different heights in the solar atmosphere, providing a potential probe of where flare energy is deposited. Despite this, there has been limited study of spectral variability in Lyα during flares, with no comparison of Lyα spectral variability to the flare heating which drives it [1,2]. Two M class flares were investigated in a multi-instument study, with Lyα spectra from SORCE/SOLSTICE being compared to nonthermal heating determined from RHESSI HXR spectra, providing insight into the relationship between nonthermal heating and spectral enhancements in different parts of the Lyα line. SDO/AIA 1600 Å images further supplemented our study of one flare, providing further insights into what drove spectral Lyα enhancements.

SOLSTICE OBSERVATIONS:

Newly available data from the Solar-Stellar Irradiance Comparison Experiment on the Solar Radiation and Climate Experiment (SORCE/SOLSTICE) provides rare spectrally-resolved Lyα flare observations, presenting a unique opportunity to compare Lyα spectral variability to nonthermal flare heating. SOLSTICE performed ~1 hour sequences of high-cadence scans once per day, each scan rastering over the Lyα line for ~67 s at a wavelength resolution of 0.35 Å. Flares observed by SOLSTICE high-cadence scans, Geostationary Operational Environmental Satellites' Extreme Ultraviolet Sensor E (GOES/EUVS-E) and the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) were identified in order to perform a multi-instrument study of flares with Lyα spectra. From these criteria two flares were selected for study: the M8.3 SOL20100212T11:19 and the M5.3 SOL20120704T09:47.

For each flare, Lyα spectra were divided into wavelength-integrated spectral bands, probing spectral variability in different parts of the Lyα line (Figure 1). Lightcurves of each band are shown in Figure 2. Peak enhancements in the wing bands were between 15.8-25.4% and between 9.5-16.0%, for SOL20100212 and SOL20120704 respectively, with respective peak enhancements of 2.9% and 4.3% in the Line Core band. Red enhancement asymmetry was seen at the impulsive peak of both flares, with this asymmetry changing to blue post peak in SOL20120704.

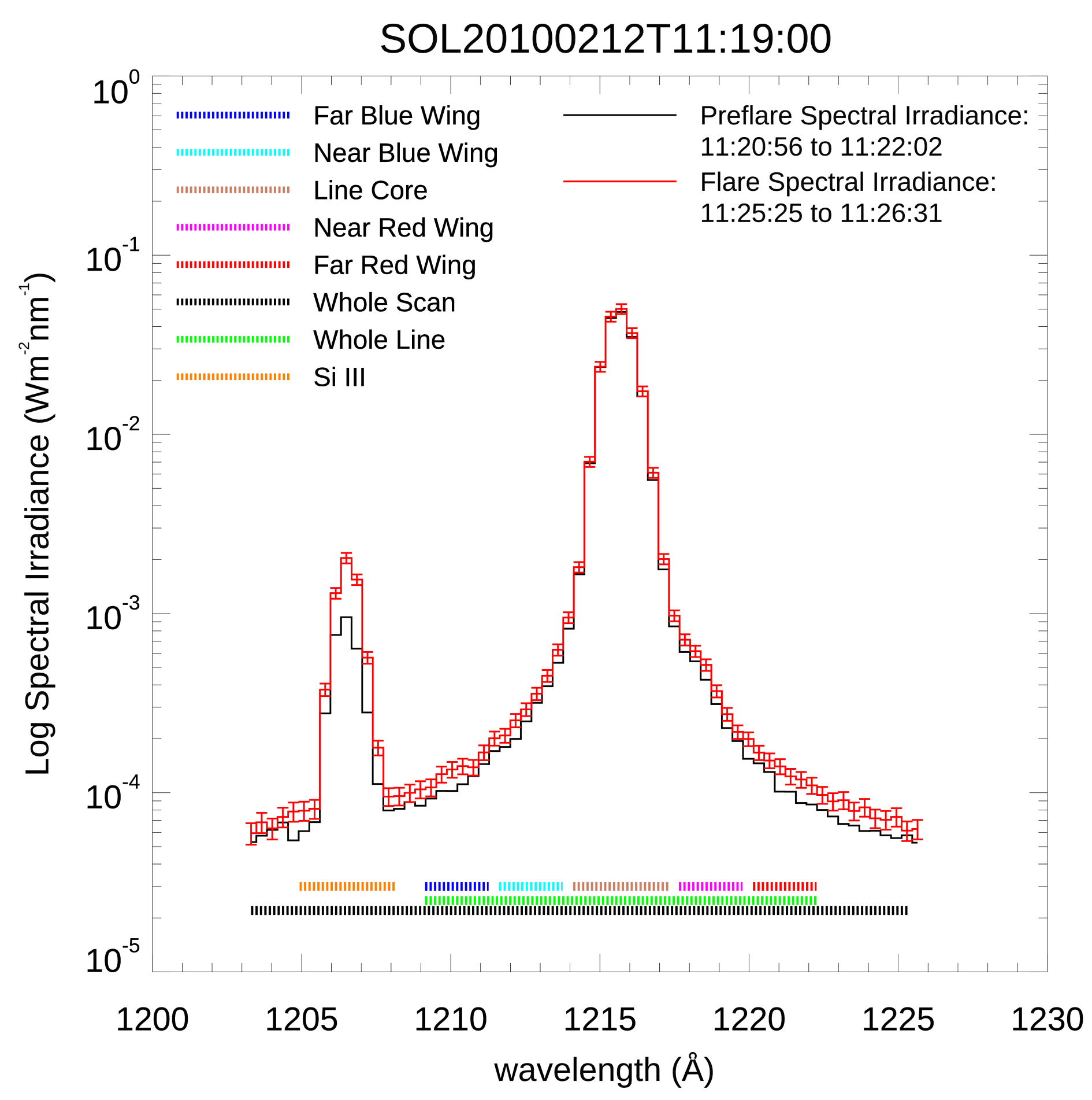

Figure 1. SOLSTICE Lyα line profile during SOL20100212. A raster taken at peak emission is plotted in red, with a preflare profile plotted in black. The wavelength range of each SOLSTICE band is illustrated by dashed lines.

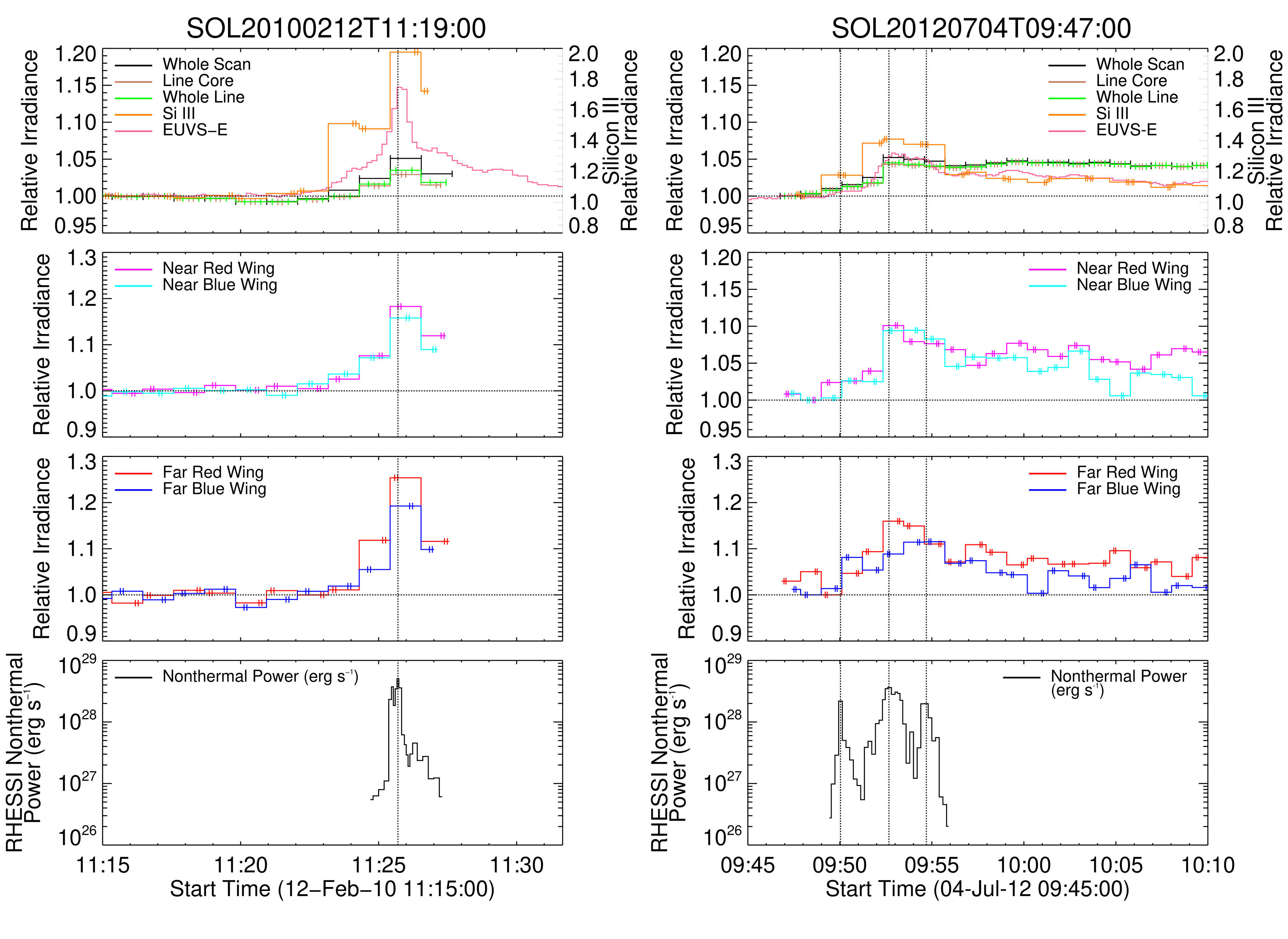

Figure 2. SOLSTICE band (defined in Figure 1) and EUVS-E lightcurves, with nonthermal power from RHESSI. Peaks in nonthermal power are illustrated by dashed lines.

RHESSI & SDO/AIA OBSERVATIONS:

HXR spectra from RHESSI were fit with a nonthermal electron distribution under the Collisional Thick Target Model in OSPEX, providing the properties (e.g. spectral index) of nonthermal electrons that drove enhancement across the Lyα line during the flares studied. Imaging from the 1600 Å channel of the Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) was used to supplement Lyα and HXR observations during SOL2012-07-04. The methods of Kazachenko et al. (2017) [3] were employed to desaturate these images. In these images flare emission was seen in both ribbons and in a bright filament-eruption (Figure 3).

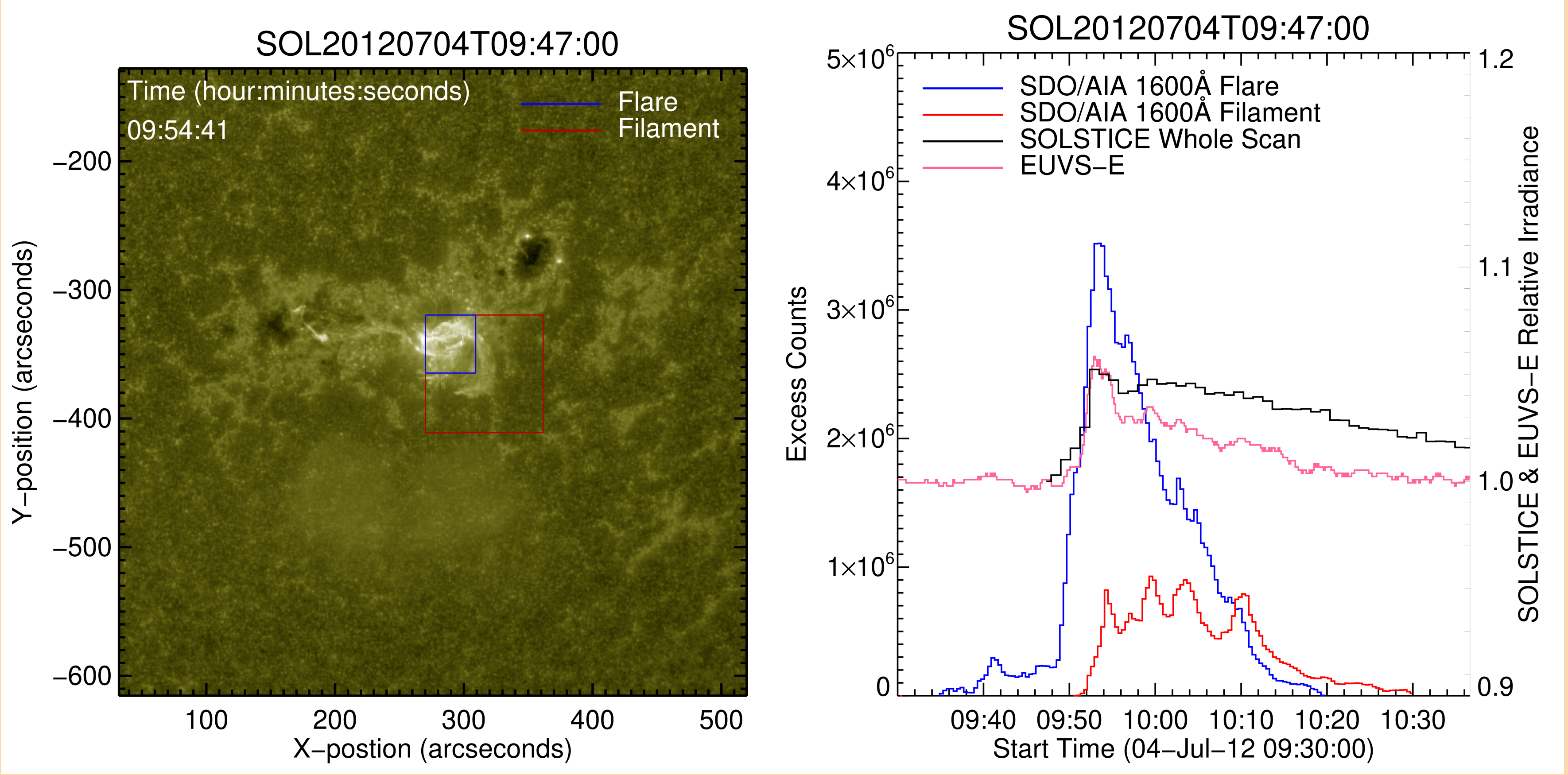

Figure 3. Left: Desaturated AIA 1600 Å image of SOL2012-07-04, flaring region contained with blue box and region of filament-eruption contained within red box. Right: Lightcurves of AIA 1600 Å excess counts for SOL2012-07-04 flare (blue) and filament (red) regions. Lyα relative irradiance is additionally shown for EUVS-E and the SOLSTICE Whole Scan band in pink and black, respectively.

KEY RESULTS & CONCLUSIONS

- Spectral enhancements across the Lyα line observed with SOLSTICE correlated well in time with the injection of nonthermal energy from flare electrons to the solar atmosphere (Figure 2)

\+ Lyα flare enhancements across the line profile are driven impulsively via interaction of nonthermal flare electrons with ambient hydrogen in the chromosphere

- Lyα wings were enhanced relatively more in SOL20100212, which had a harder electron distribution (δ=5.58 vs δ=8.34) than SOL20120704

\+ Negative trend in wing enhancements with δ, similar to trend seen in broadband observations [4], harder electron distributions may deposit more energy where the Lyα wings form

- AIA images (Figure 3) show emission from a filament-eruption correlating with a blue enhancement asymmetry seen in the Lyα line during SOL20120704

\+ Thermally driven emission from upflowing material in the filament likely contributed to this blue asymmetry in Lyα

These observations may serve to inform future research using radiation hydrodynamic simulations. Furthermore, upcoming Lyα spectral instruments, e.g. Solar-C's Extreme Ultraviolet High-Throughput Spectroscopic Telescope (EUVST), should provide more robust statistics on Lyα spectral variability during flares.

[1] Woods et al. (2004) , doi 10.1029/2004GL019571
[2] Canfield et al. (1980), doi 10.1007/BF00149811
[3] Kazachenko et al. (2017), doi 10.3847/1538-4357/aa7ed6
[4] Greatorex et al. (2023), doi 10.3847/1538-4357/acea7f

Contact: lmajury01@qub.ac.uk