

# Modelling the Recombination Continua Observed By SDO/EVE During an X-Class Solar Flare Using RADYN

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# Abstract

The EUV Variability Experiment (EVE) onboard SDO is now making routine observations of the solar EUV irradiance on flare timescales. While these observations are important for determining the Sun's influence on the geospace environment, they also provide a crucial diagnostic of the flaring chromosphere during the impulsive phase. Milligan et al. (2012) presented new observations from EVE which showed unambiguous, spectrally and temporally-resolved detections of enhanced free-bound (and free-free) continua during the first X-class flare of Solar Cycle 24; an X2.2 flare that occurred on 15 February 2011. By constructing lightcurves of the Lyman continuum of H, the He I and He II continua, and the Ly- $\alpha$  and He II 304Å lines, the authors showed that they peaked in concert with the 25-100 keV emission observed by RHESSI, indicating a chromospheric origin. Allred et al. (2005; RADYN) predicted that these recombination continua should energetically dominate over line emission. By fitting the RHESSI HXR spectra for the same event, we were able to model the response of the chromosphere to the derived electron beam parameters using RADYN. The resulting simulated EUV continua could then be directly compared to the observations from EVE. This will ultimately help determine the depth of the solar atmosphere at which the heating takes place, and the mechanism responsible. Here we present the similarities and differences between the observed and modelled emission, and suggest possible explanations.



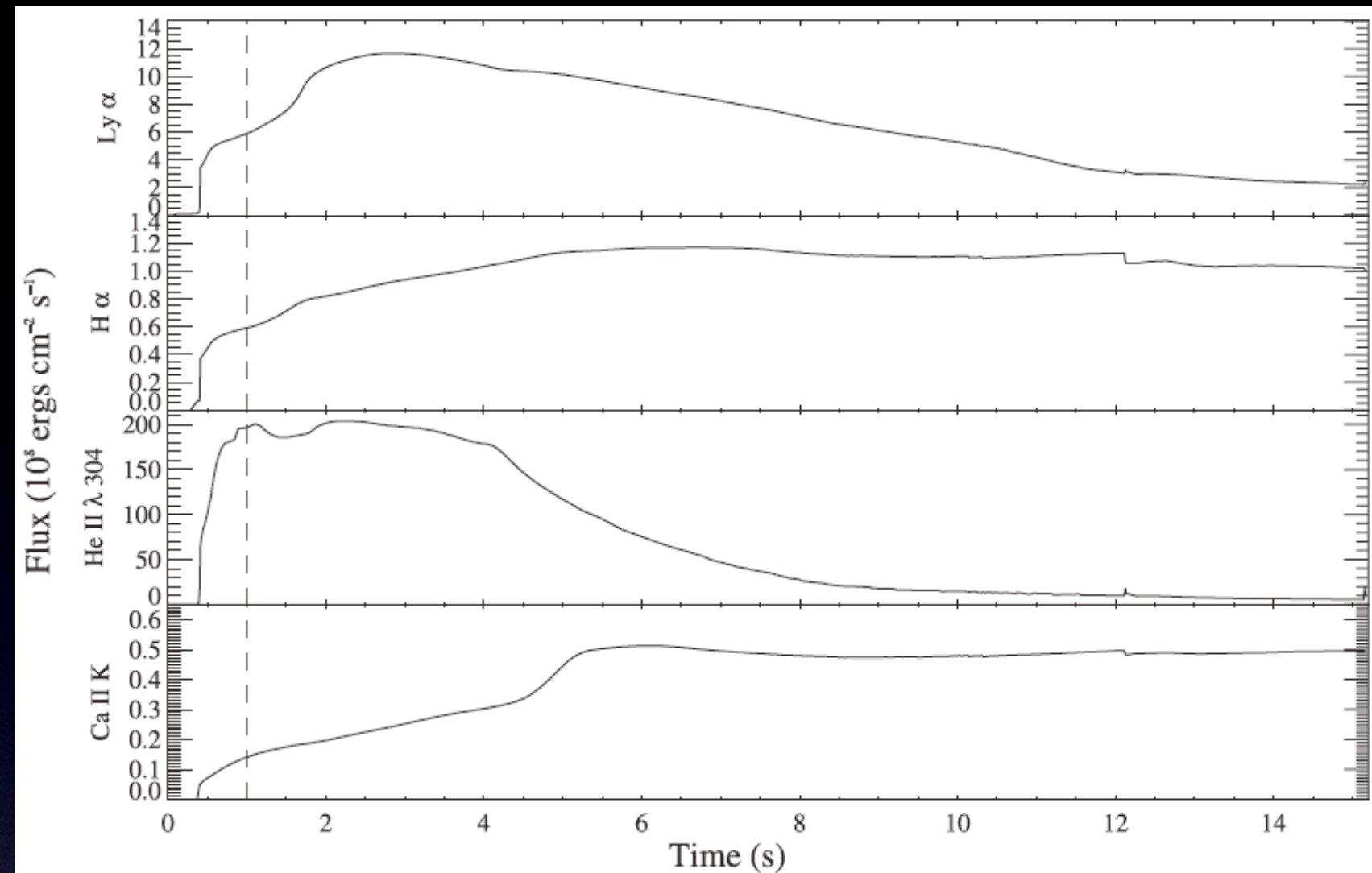
## Lines

Ly- $\alpha$

H $\alpha$

He II

Ca II



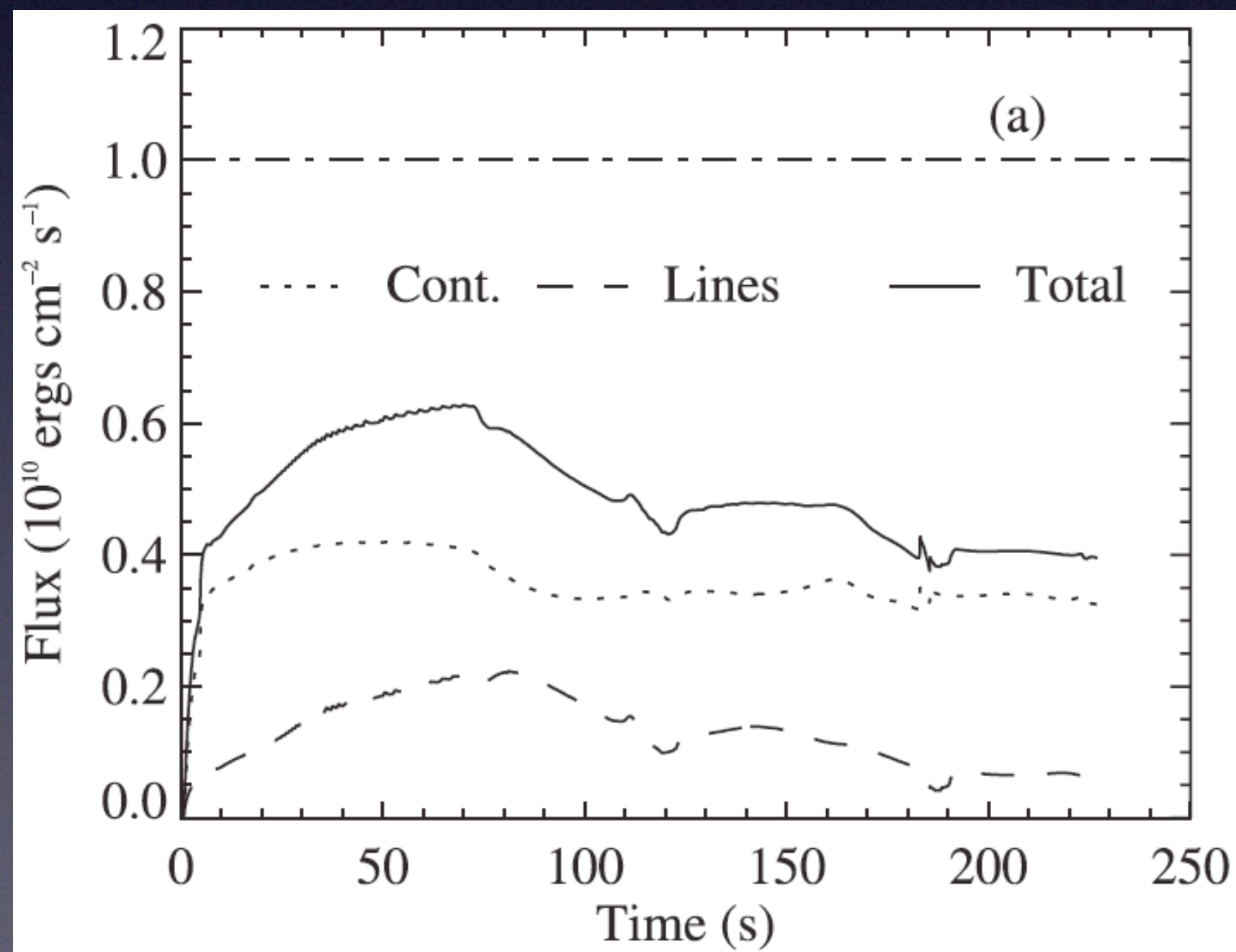
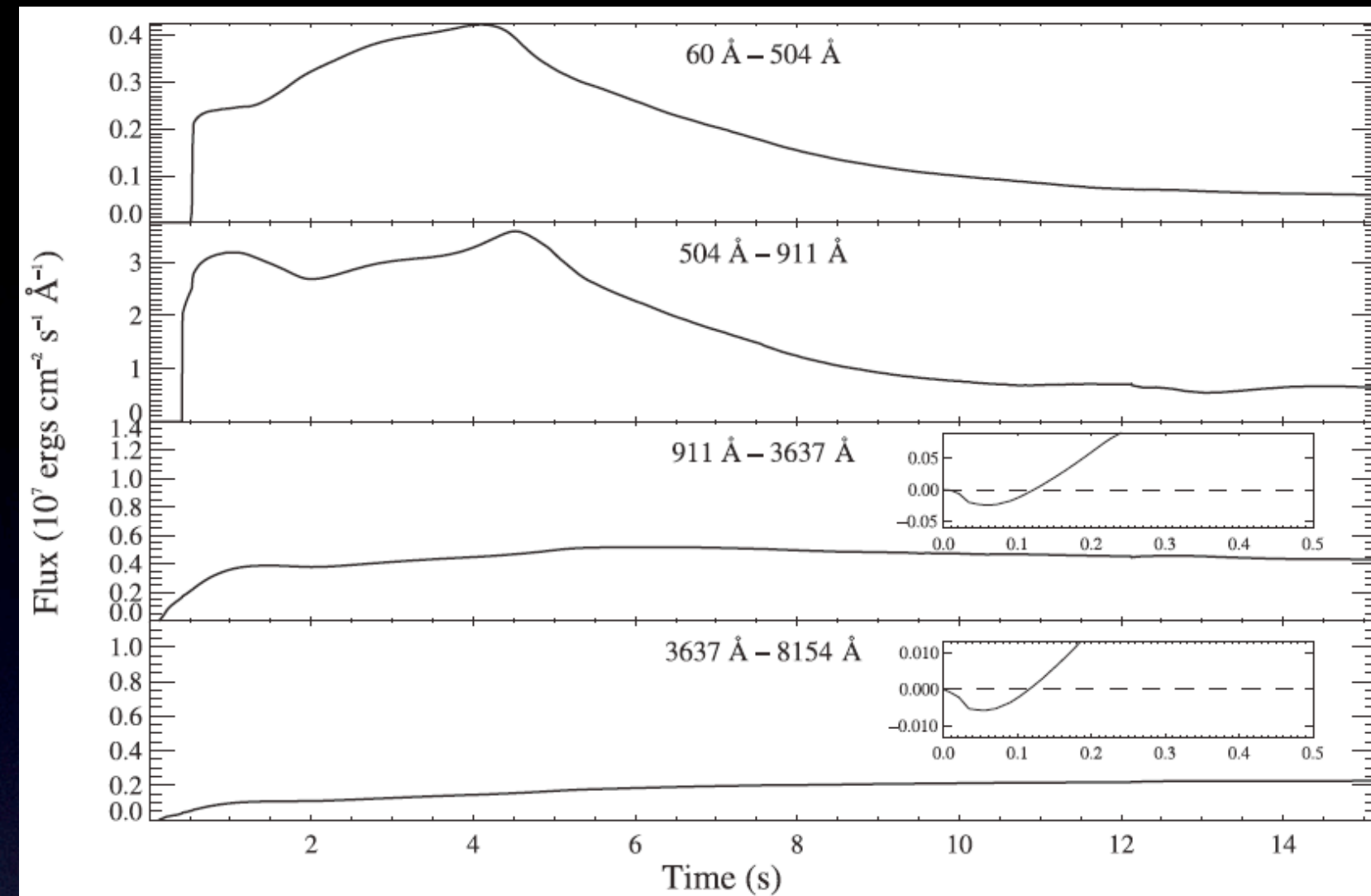
## Continua

He I + He II

Ly + He II

Balmer+He I+Ca II

Paschen+He I

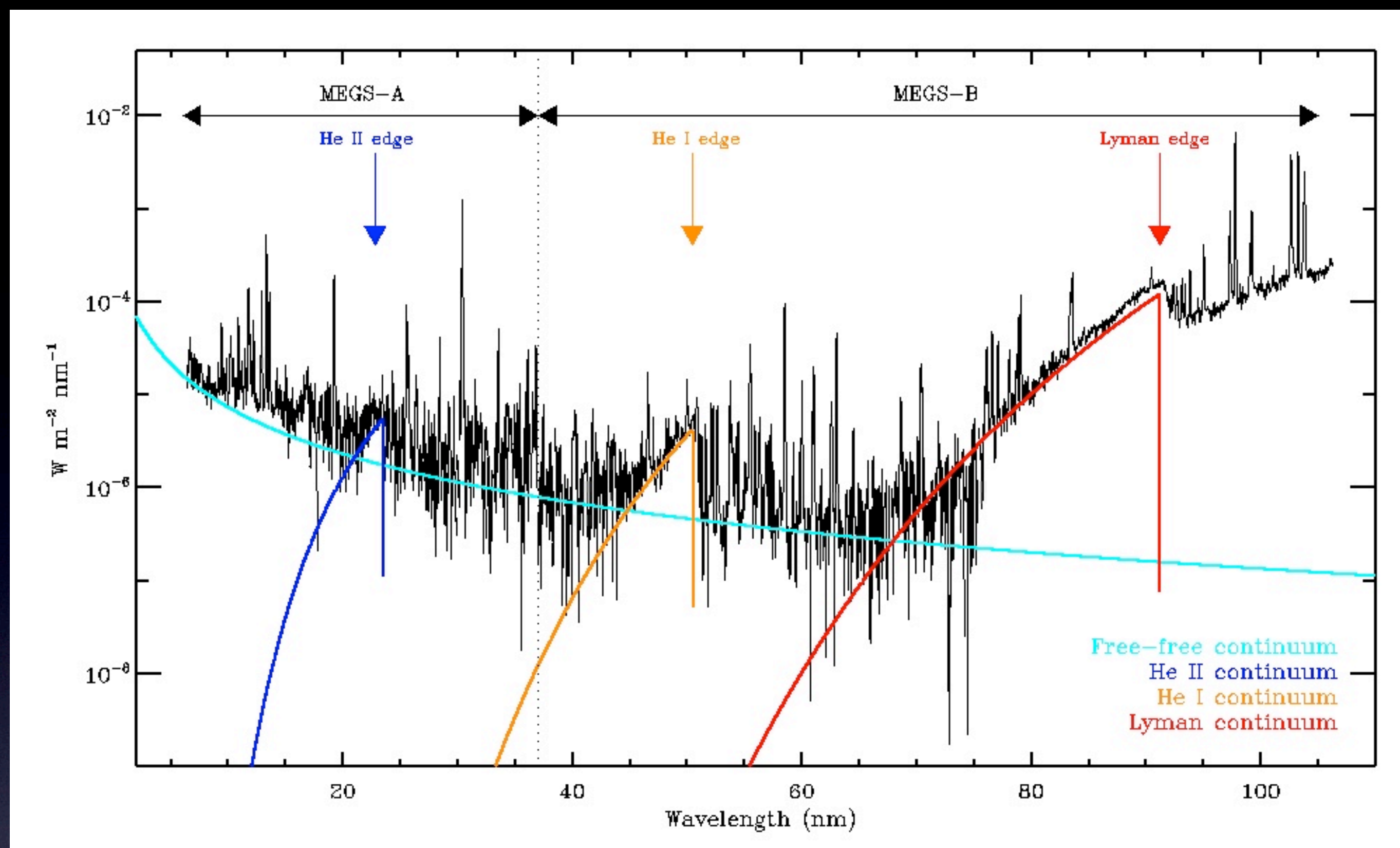


Radiative hydrodynamic simulations of Allred et al. (2005) state that the majority of energy deposited in the chromosphere by nonthermal electrons is radiated away via continuum emission.

The Lyman, He I and He II continua (as well as the Ly- $\alpha$  and He II 304Å lines, highlighted by red boxes above) are now routinely observed by SDO/EVE, offering a critical testing of these models.

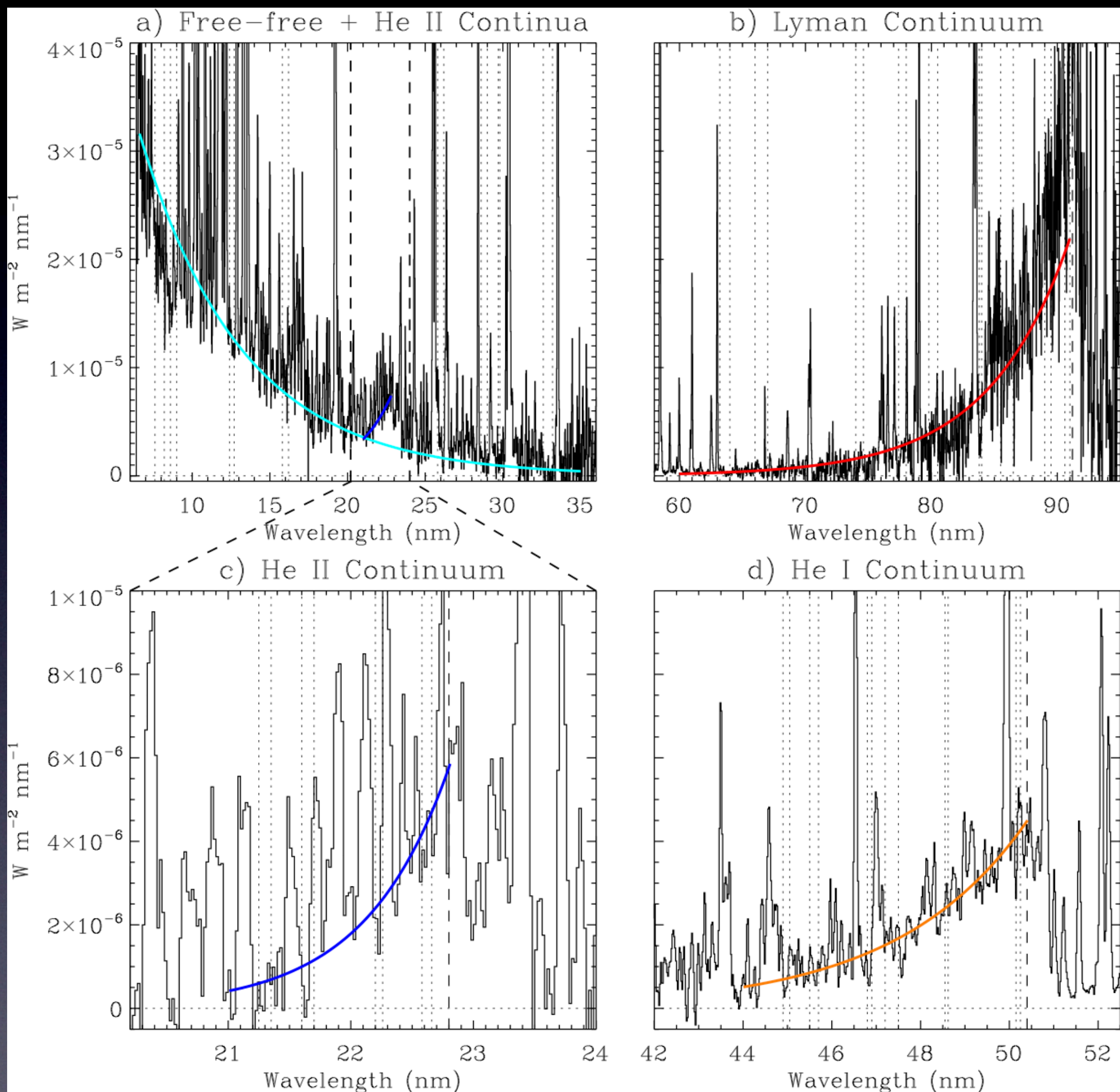
←lightcurves in response to an arbitrary beam flux density of  $10^{11}$  ergs cm $^{-2}$  s $^{-1}$





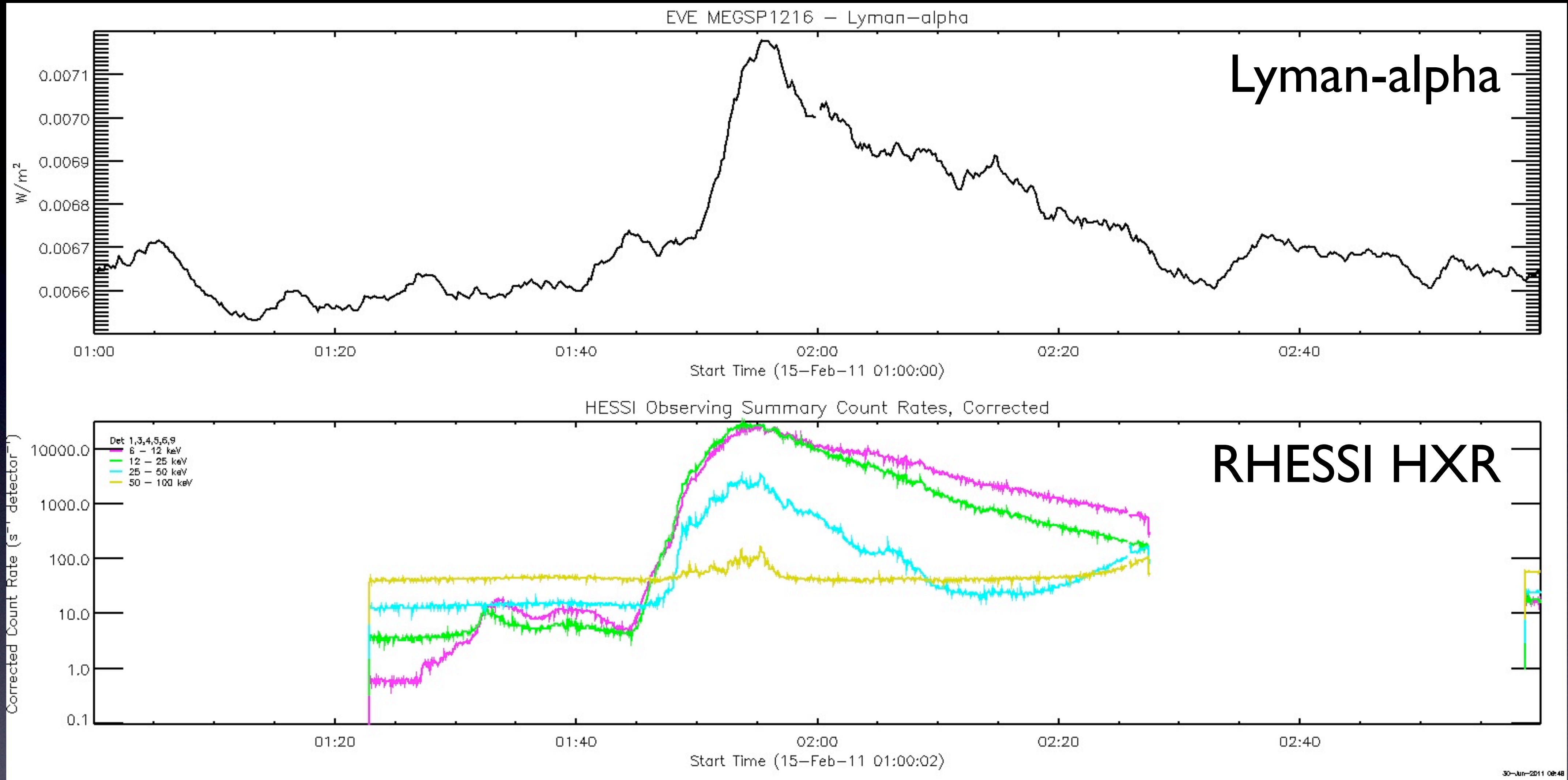
- The He II continuum and He II 304Å line are observed continuously with EVE's MEGS-A component at 10s cadence. The Lyman and He I continua (and Ly- $\alpha$  line; MEGS-P) are only observed by its MEGS-B component at times of increased solar activity due to detector degradation. MEGS-B observations are therefore crucial to these studies
- Above is the complete EVE spectrum (Version 2 data) at the peak of the X2.2 flare on 15 February 2011 after subtracting out a pre-flare profile. Each of the continua are noted.





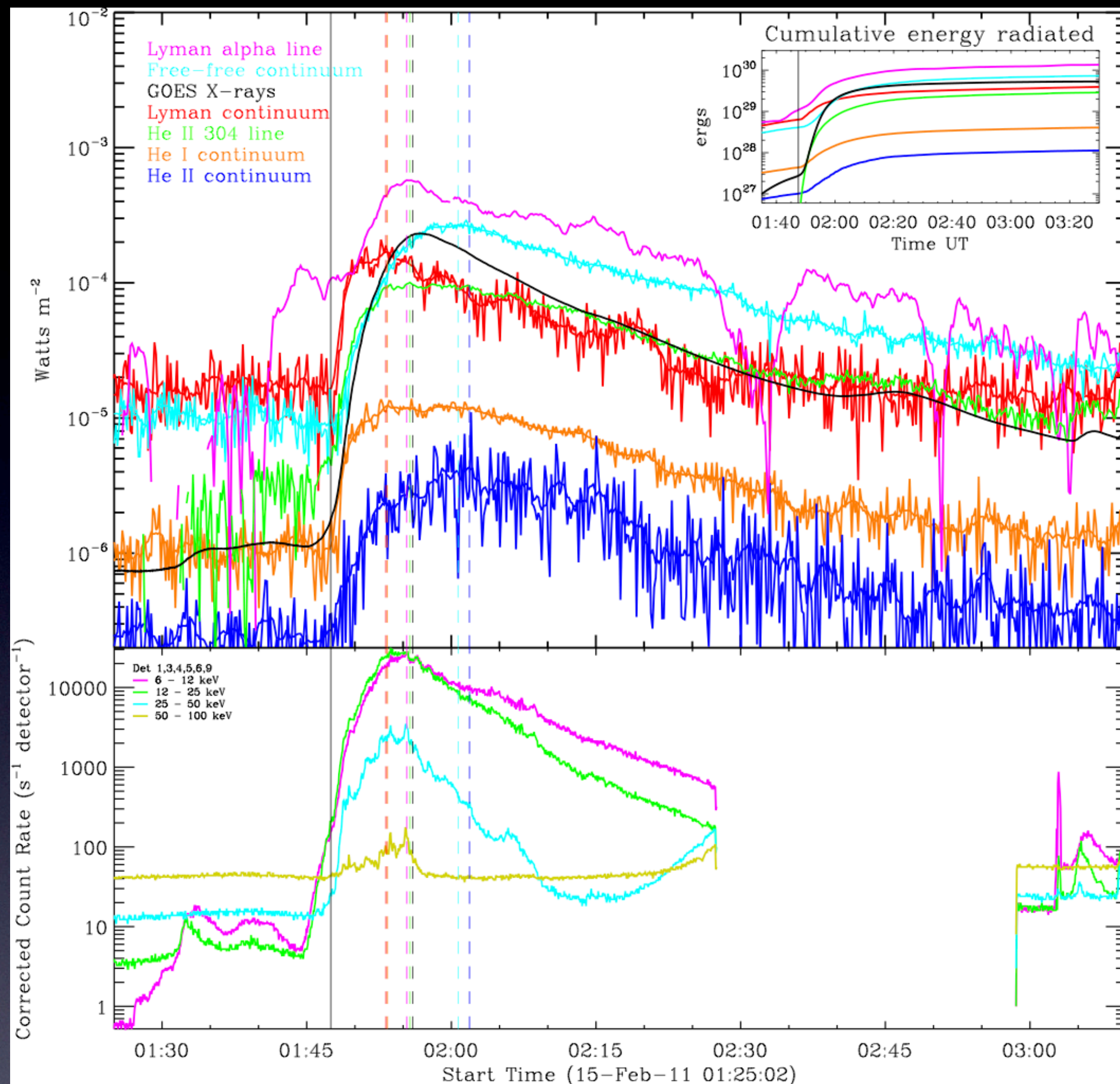
- In order to construct lightcurves of the total free-bound emission, the EVE data blue-ward of each recombination edge were fit with an exponential function
- The entire MEGS-A wavelength range was also fit to measure the free-free contribution, which was subtracted from the data in order to fit the He II continuum
- Previously, a synthetic spectrum from CHIANTI was used to determine the line-free portions of the spectra. Recently, however, Milligan & McElroy (2013; see other poster) have developed a more robust technique which will be applied to future analyses
- Go to [http://star.pst.qub.ac.uk/~rm/20110215/apjl\\_movie.mov](http://star.pst.qub.ac.uk/~rm/20110215/apjl_movie.mov) for a movie of the fits to the continuum during the 15 Feb 2011 flare





EVE's MEGS-P channel and RHESSI were also observing during this event. The Ly- $\alpha$  emission was found to peak in time with the HXR emission. Although the MEGS-P diode is broadband (10 nm), more than 99% of the detected emission is due to solar Ly- $\alpha$  after accounting for non-solar sources (e.g., geocoronal emission).



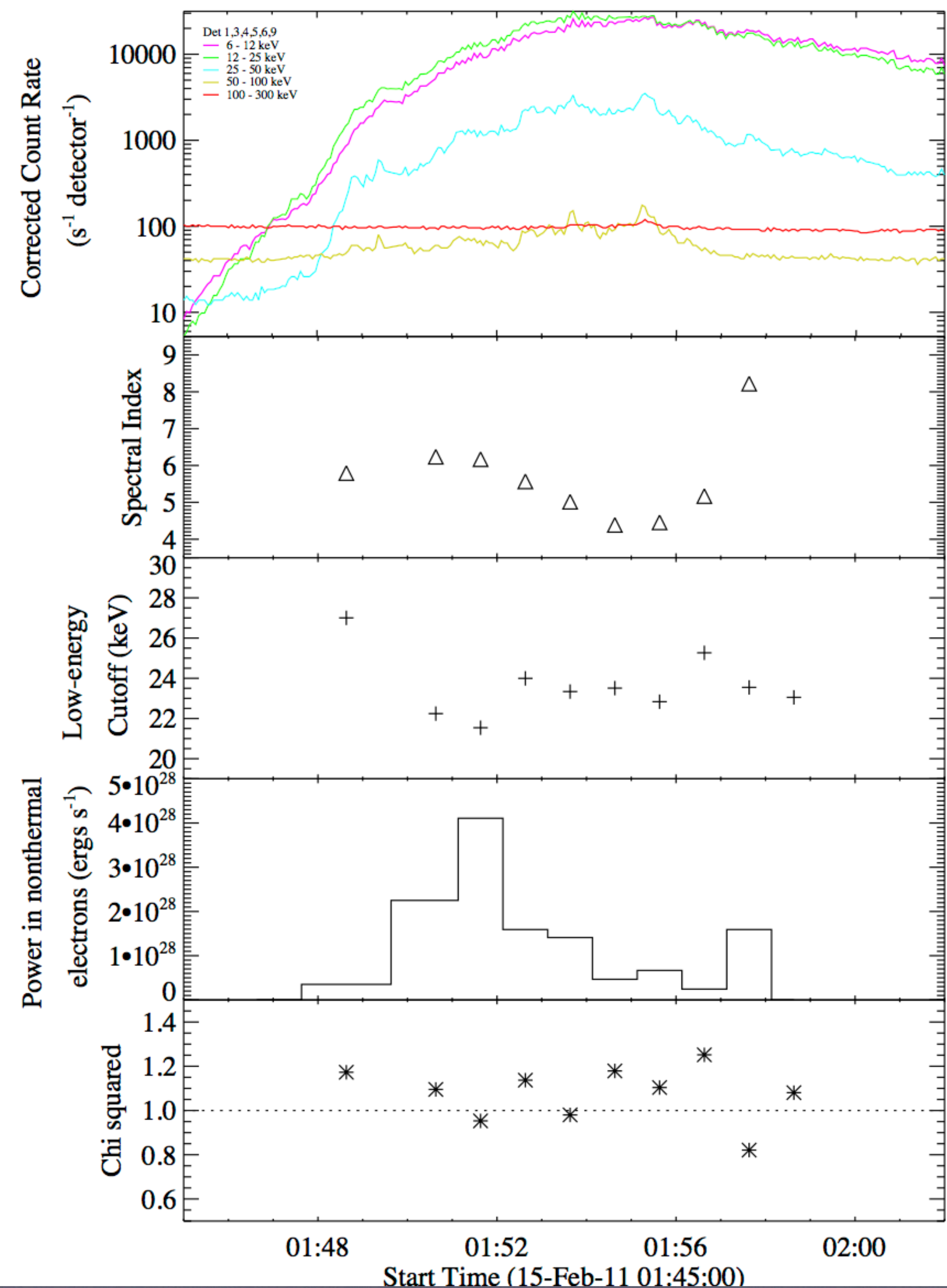
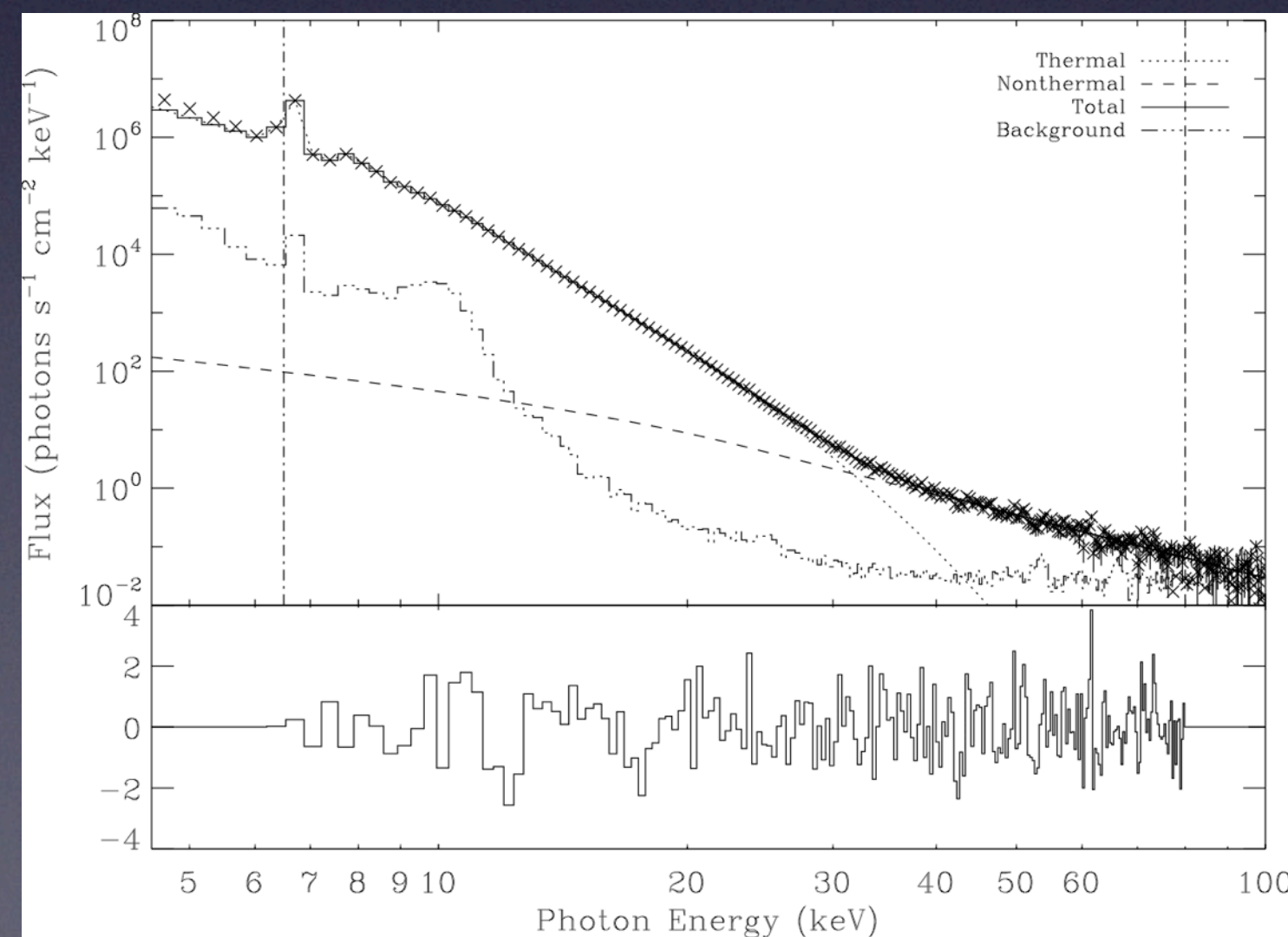


	$\lambda$ (Å)	Total Energy (ergs)
Lyman- $\alpha$	1166-1266	$1 \times 10^{30}$
Free-free continuum	65-350	$8 \times 10^{29}$
GOES X-rays	1-8	$5 \times 10^{29}$
Lyman continuum	600-912	$4 \times 10^{29}$
He II 304	303-305	$3 \times 10^{29}$
He I continuum	440-504	$4 \times 10^{28}$
He II continuum	210-228	$1 \times 10^{28}$

Each of the lightcurves peaked around the time of the HXR emission observed by RHESSI (apart from the free-free and He II continua) suggesting excitation due to nonthermal electrons. Integrating over the flare duration gave the total energy emitted via each process (Milligan et al. 2012, ApJL, 748, L14)

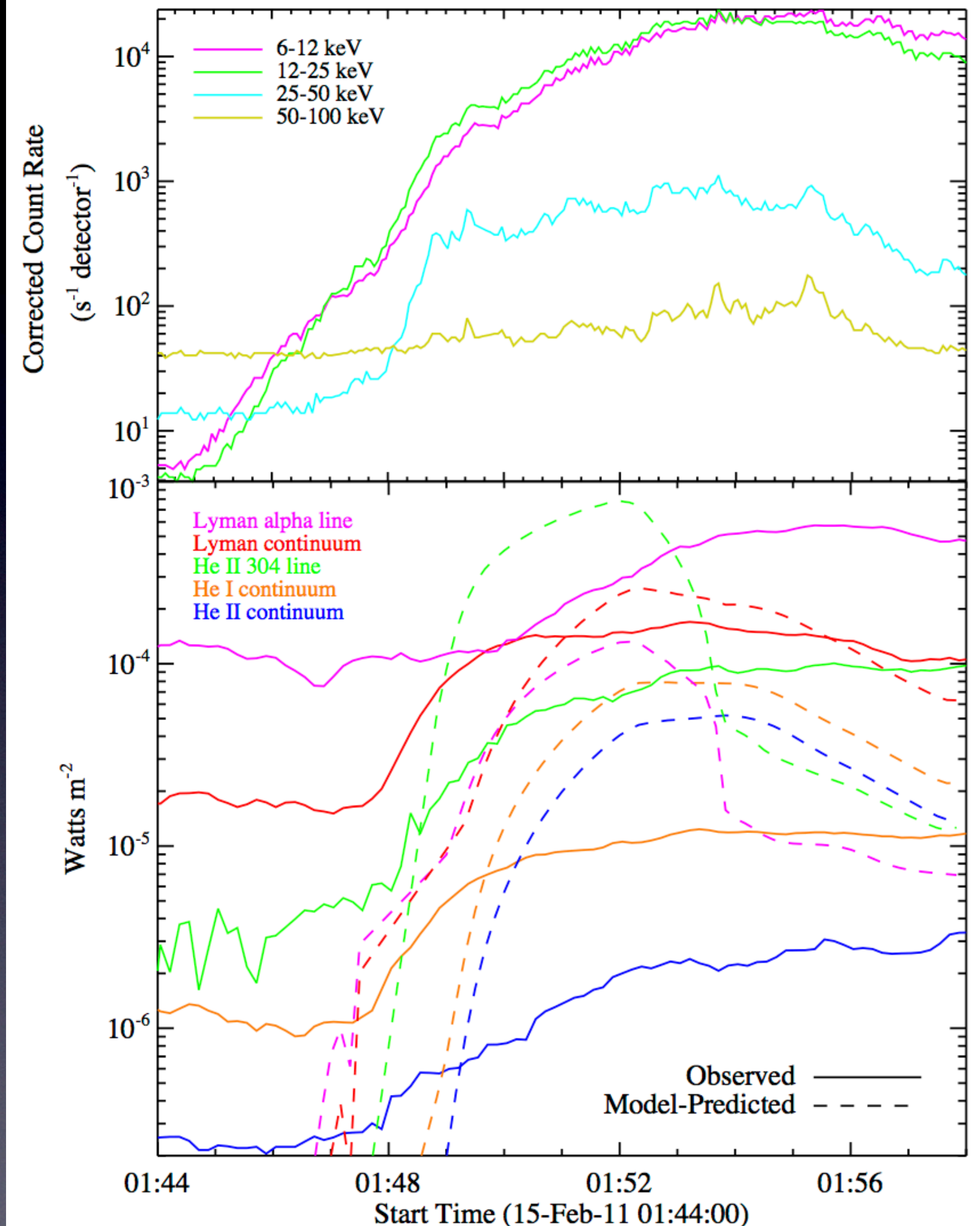


- RHESSI spectra (below) for the 15 Feb 2011 event were fit with multi-thermal, thick target, and `drm_mod` components, as well as correcting for albedo and pulse pile-up
- This was repeated for 10x60s intervals over the HXR peak to establish the properties of the electron beam ( $\delta$ ,  $E_C$ ,  $P_{nth}$ ) as a function of time (right)
- These parameters, and an assumed footpoint area of  $10^{17} \text{ cm}^2$ , were used to drive the numerical model of RADYN to simulate the chromospheric response to heating by a beam of injected electrons





- The simulated chromospheric lightcurves from RADYN (dashed lines, bottom panel) were then directly compared to the observed ones from EVE (solid lines)
- Both similarities and differences were found:
  - the predicted Lyman continuum profile (red) appeared to agree reasonably well with that observed by EVE, and the *relative* intensities of each of the free-bound continua were in overall agreement, although the He I (orange) and He II (blue) continua were overestimated by about an order of magnitude
  - the He II 304Å line (green) was predicted to be stronger than the Ly- $\alpha$  line (purple), while observationally the reverse was true
  - the simulated lightcurves began to decay much quicker than was observed, particularly for the line emission





- What are the possible explanations for the discrepancies between the observed and predicted EUV emission for the 15 February 2011 flare?
  - Is it due to uncertainties in the EVE calibration? Will Version 3 of the EVE data, analysed using the updated techniques of Milligan & McElroy (2013, submitted), provide a better agreement, particularly for the Ly- $\alpha$  line and Lyman continuum observed by MEGS-B?
  - Could the measured value of the low energy cutoff in the RHESSI spectra be incorrect? Can this type of study help constrain this parameter?
  - How does the value of the footpoint area affect the value of the beam flux density, and therefore the simulated response? How would using measured values from RHESSI or Hinode/SOT change the resulting modelled emission?
  - Has EUV backwarming been under/over-estimated in the simulations?
  - Will the inclusion of proton beams and/or return currents in the RADYN code produce a closer agreement?
- How does the 15 February 2011 X-class flare compare with other events?



# Future work

- We aim to repeat this study by applying updated data analysis techniques to Version 3 of the EVE data, and extending it to the 1600Å and 1700Å channels on AIA, and the red/green/blue WL channels on Hinode/SOT also available for this event (see Kerr & Fletcher 2013)
- Measurements of the footpoint area will also be determined from RHESSI images
- We will produce simulated lightcurves with and without backwarming, proton beams, and return currents with which to compare to the updated observed ones



# Summary

- Although primarily designed to measure changes in the geoeffective component of solar EUV irradiance, EVE also offers the ability to measure changes in the recombination continua that are believed to be the primary radiator of energy deposited in the solar chromosphere by nonthermal electrons during a flare's impulsive phase
- Fitting HXR spectra from RHESSI can be used to determine the properties of the associated nonthermal electrons. These parameters can be used to drive various chromospheric heating models, the results of which can be directly compared with EVE observations
- In this study we used the 1-D radiative hydrodynamic model of Allred et al. (2005,2006; RADYN) to model the chromospheric response to measured beam parameters from RHESSI and compared the resulting emission with EVE observations. This will ultimately shed light on the depth of the solar atmosphere at which this heating takes place, and the mechanism responsible