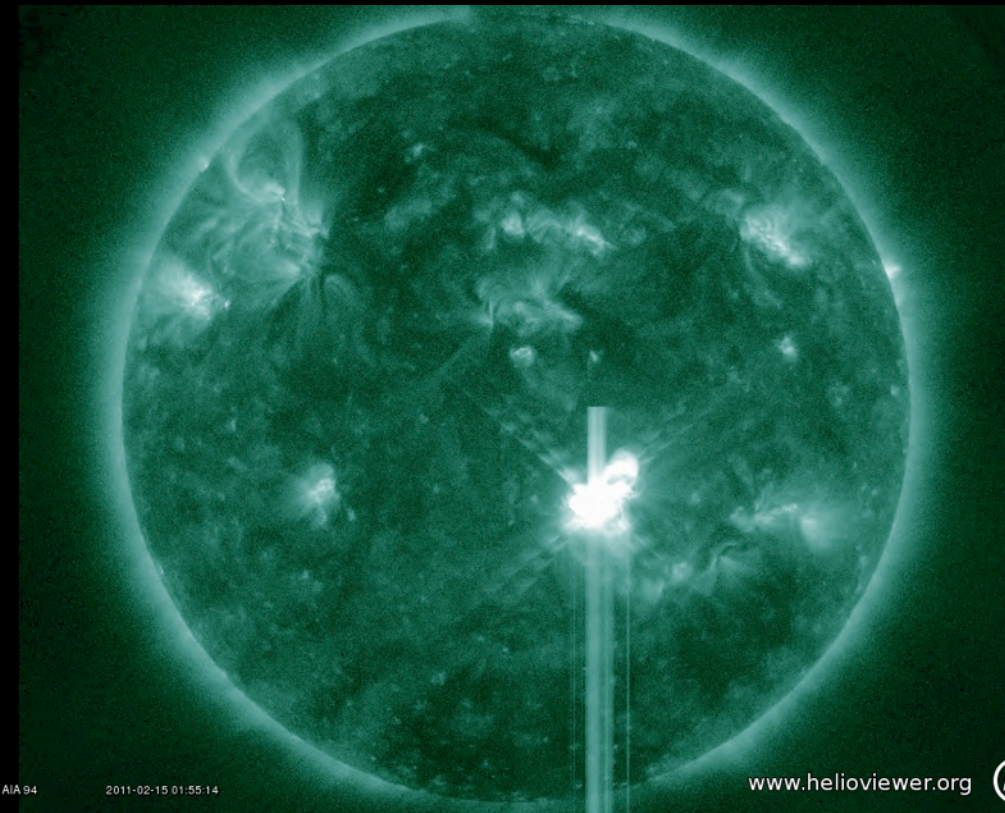


# Continuum Contributions to the SDO/AIA Passbands During Solar Flares

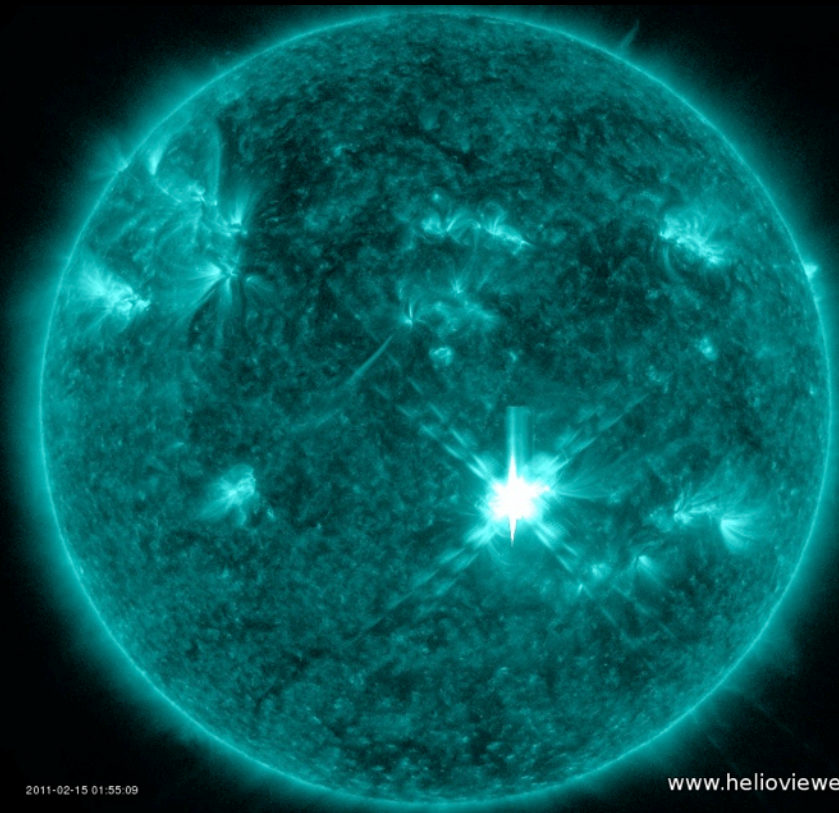
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# Abstract

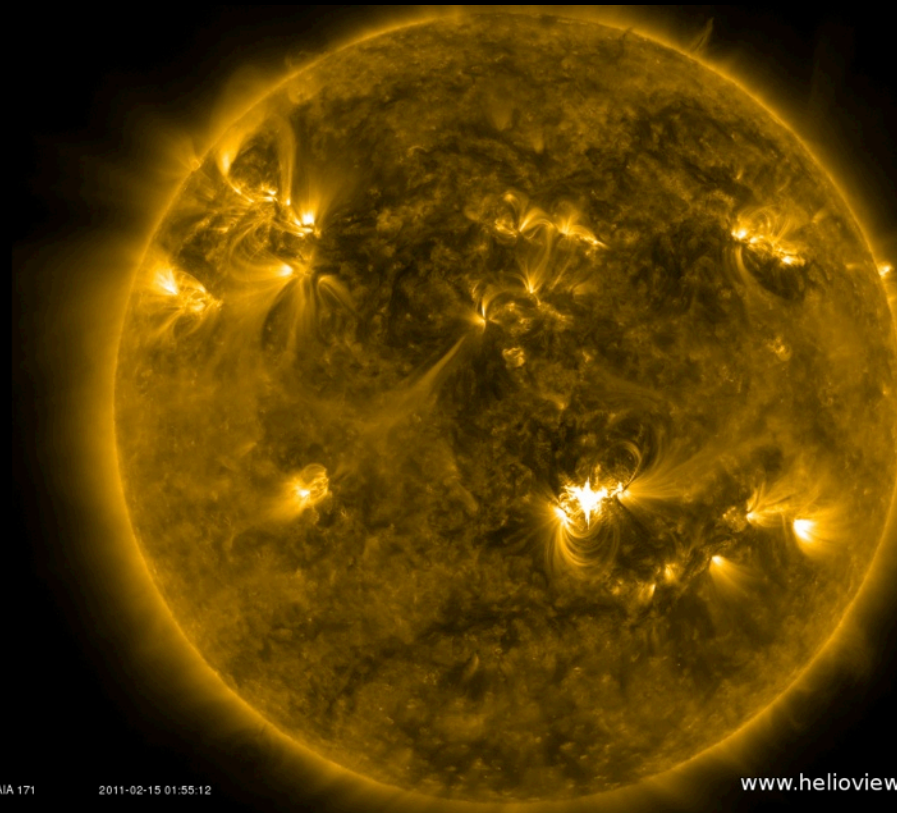
Data from the Multiple EUV Grating Spectrograph (MEGS-A) component of the Extreme Ultraviolet Experiment (EVE) onboard the Solar Dynamics Observatory (SDO) were used to quantify the contribution of continuum emission to each of the EUV channels of the Atmospheric Imaging Assembly (AIA), also on SDO, during an X-class solar flare that occurred on 15 February 2011. Both the pre-flare subtracted EVE spectra and fits to the associated free-free continuum were convolved with the AIA response functions for the seven EUV passbands at 10 s cadence throughout the course of the flare. It was found that 10–25% of the total emission in the 94Å, 131Å, 193Å, and 335Å passbands throughout the main phase of the flare was due to free-free emission. Reliable measurements could not be made for the 171Å channel due to possible coronal dimming during the event, while the continuum contribution to the 304Å channel was negligible due to the presence of the strong He II line. Up to 50% of the emission in the 211Å channel was found to be due to free-free emission around the peak of the flare, while an additional 20% was due to the recombination continuum of He II. The analysis was extended to a number of M- and X-class flares and it was found that the level of free-free emission contributing to the 211Å passband scales with respect to GOES class, increasing from 20% at the soft X-ray peak of low M-class flares to 55% during the largest X-class events. These findings suggest that the contribution of continuum emission to AIA observations during flares is more significant than that stated in previous studies which used synthetic, rather than observed, spectra. These results highlight the importance of spectroscopic observations carried out in conjunction with those from imaging instruments so that the data are interpreted accurately.



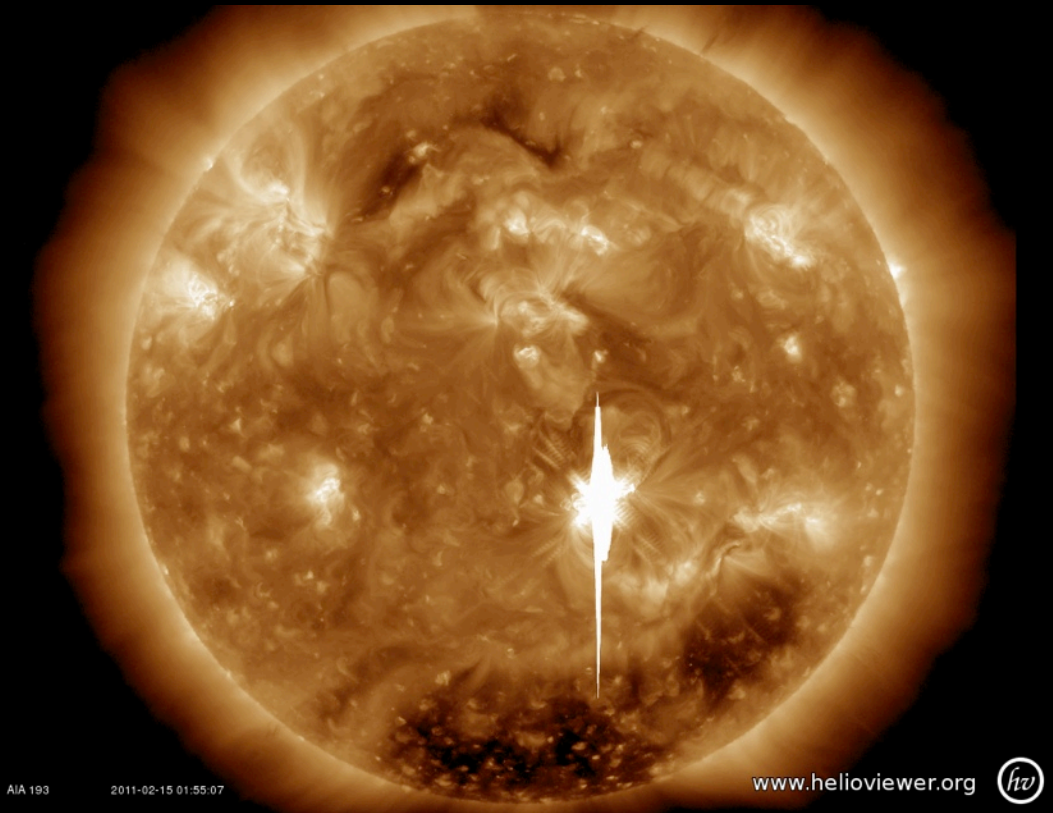
94Å: Fe XVIII



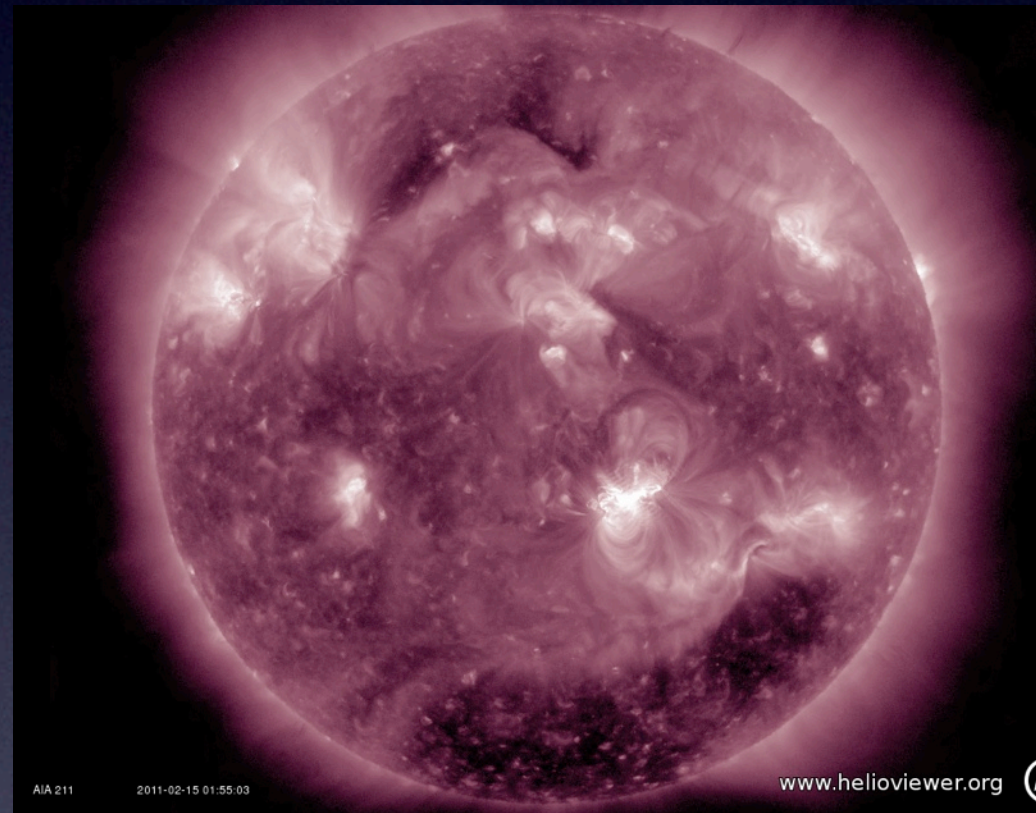
131Å: Fe XXI



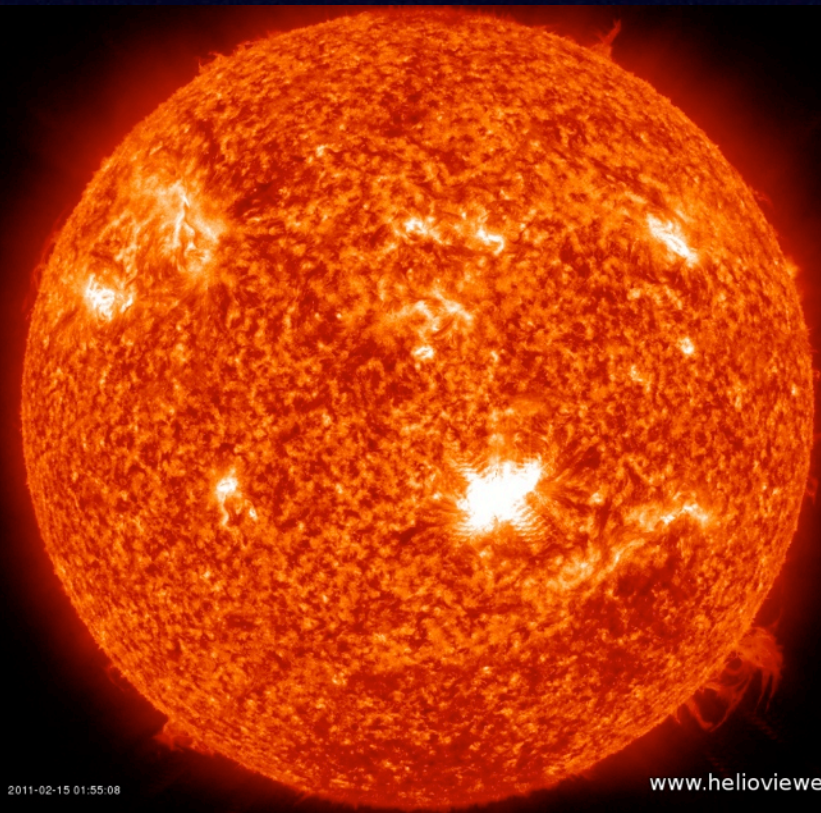
171Å: Fe IX



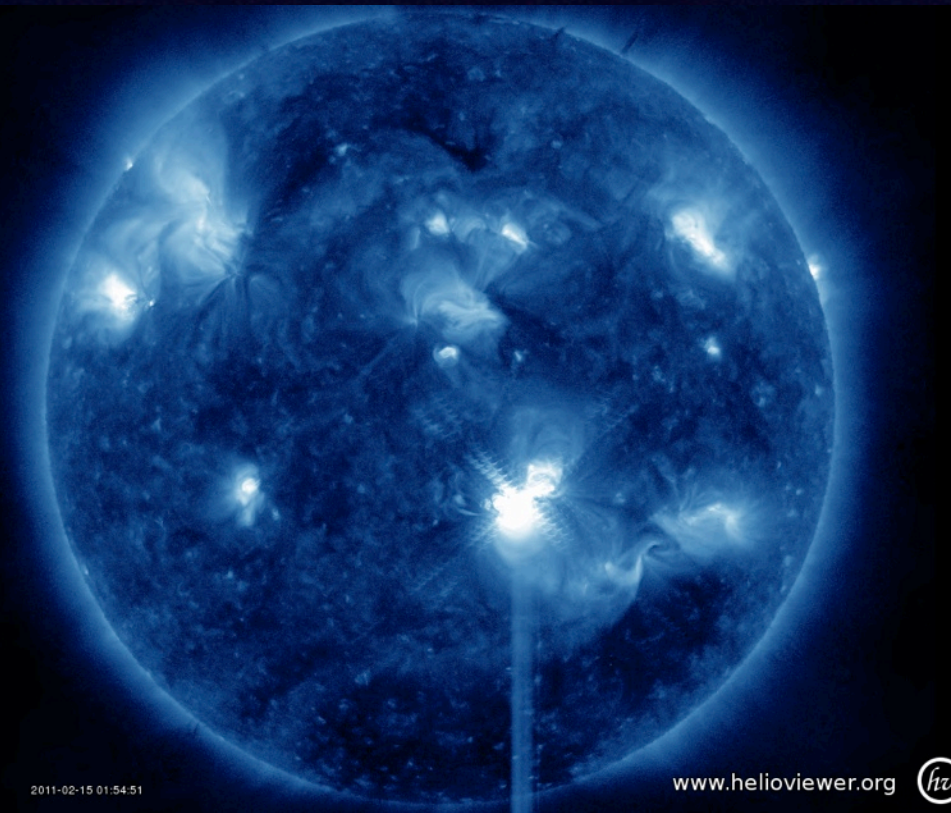
193Å: Fe XXIV



211Å: Fe XIV



304Å: He II



335Å: Fe XVI

Figure 1: Images of the X2.2 flare on 15 Feb 2011 in each of AIA's EUV passbands. The primary emission line believed to dominate each image during the flare is also given.

The passbands on SDO/AIA are broadly assumed to focus on emission from a single isothermal emission line. During solar flares, however, the emission in each passband may contain a contribution from the underlying continuum. The aim of this work was to quantify how much this continuum emission contributes to the AIA passbands during flares.

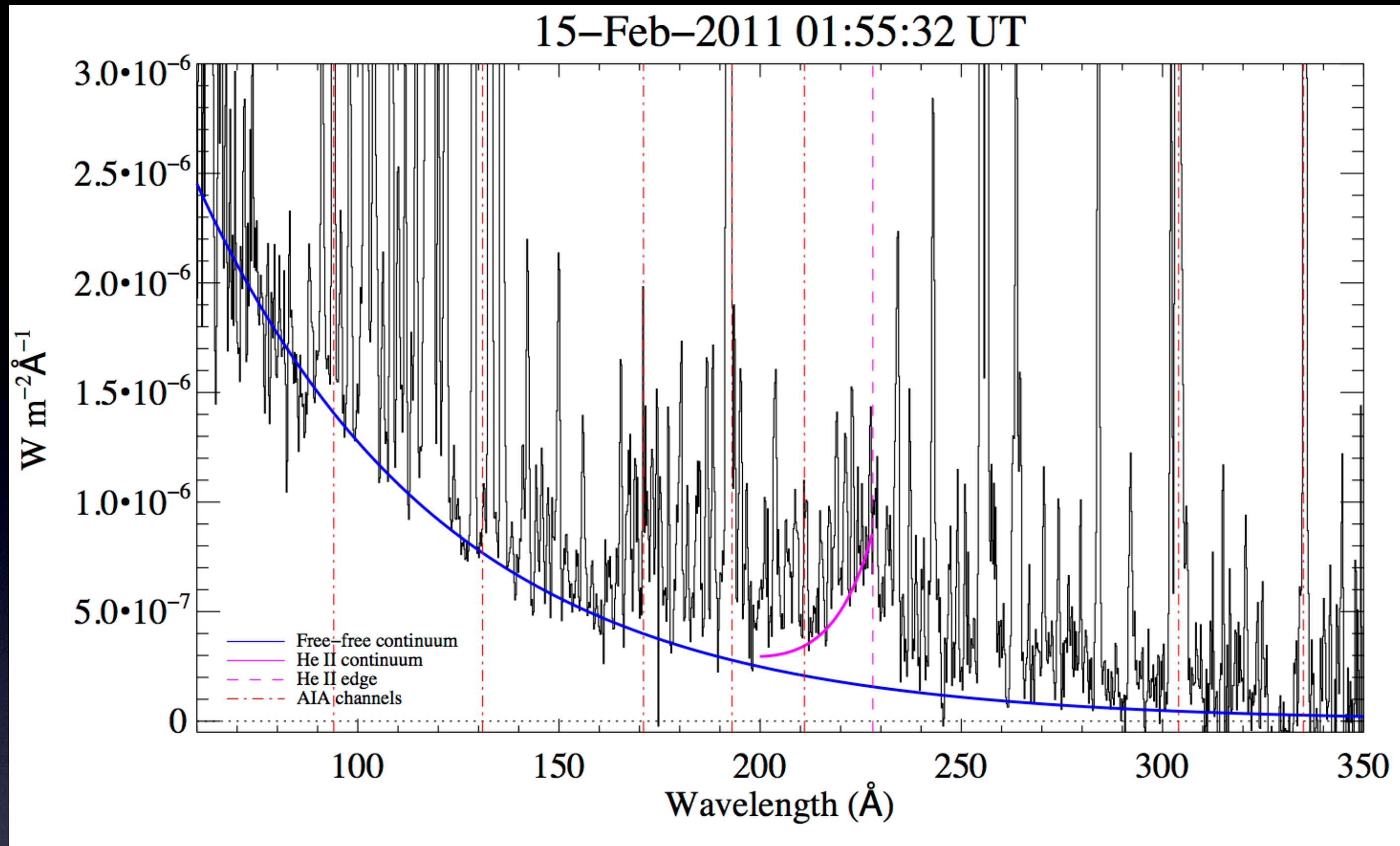


Figure 2: A spectrum from EVE MEGS-A taken at the peak of the 15 Feb. 2011 X2.2 flare. The vertical red dot-dashed lines mark the locations of the AIA passbands. The blue curve denotes the fit to the underlying free-free continuum, while the purple curve denotes the fit to the free-bound continuum of He II blueward of the recombination edge at  $228\text{\AA}$  (vertical dashed purple line).

- The EVE MEGS-A spectral range (above) contains each of AIA's EUV channels (vertical dot-dashed red lines)
- Milligan et al. (2012) showed that the free-free continuum (due to thermal bremsstrahlung in the corona; solid blue line) that spans the MEGS-A wavelength range, becomes significantly enhanced during solar flares
- By convolving fits to this continuum with the AIA response functions, the amount of continuum emission that contributes to images in each channel during flares can be determined

- The EVE spectra ( $I(\lambda, t)$ ) were differentiated twice to identify local minima (vertical dashed red lines), where  $dI/d\lambda \approx 0$  and  $d^2I/d\lambda^2 > 0$
- Three regions (grey shaded areas) were omitted from the fitting process to prevent biases :
  - $60 < \lambda < 80$  was omitted due to noise
  - $100 < \lambda < 125$  contains the pseudo-continuum around the Fe XIX-Fe XXII lines
  - $160 < \lambda < 230$  was omitted to avoid possible coronal dimming effects and the He II continuum
- The local minima were fit with an exponential function (solid blue curve), which marked out the lower envelope of the spectrum. This was taken to represent the free-free continuum
- Having subtracted out this free-free emission, the process was repeated (vertical green lines) to fit the free-bound continuum of He II (purple exponential curve) which straddles the 211Å passband (see Figure 2)

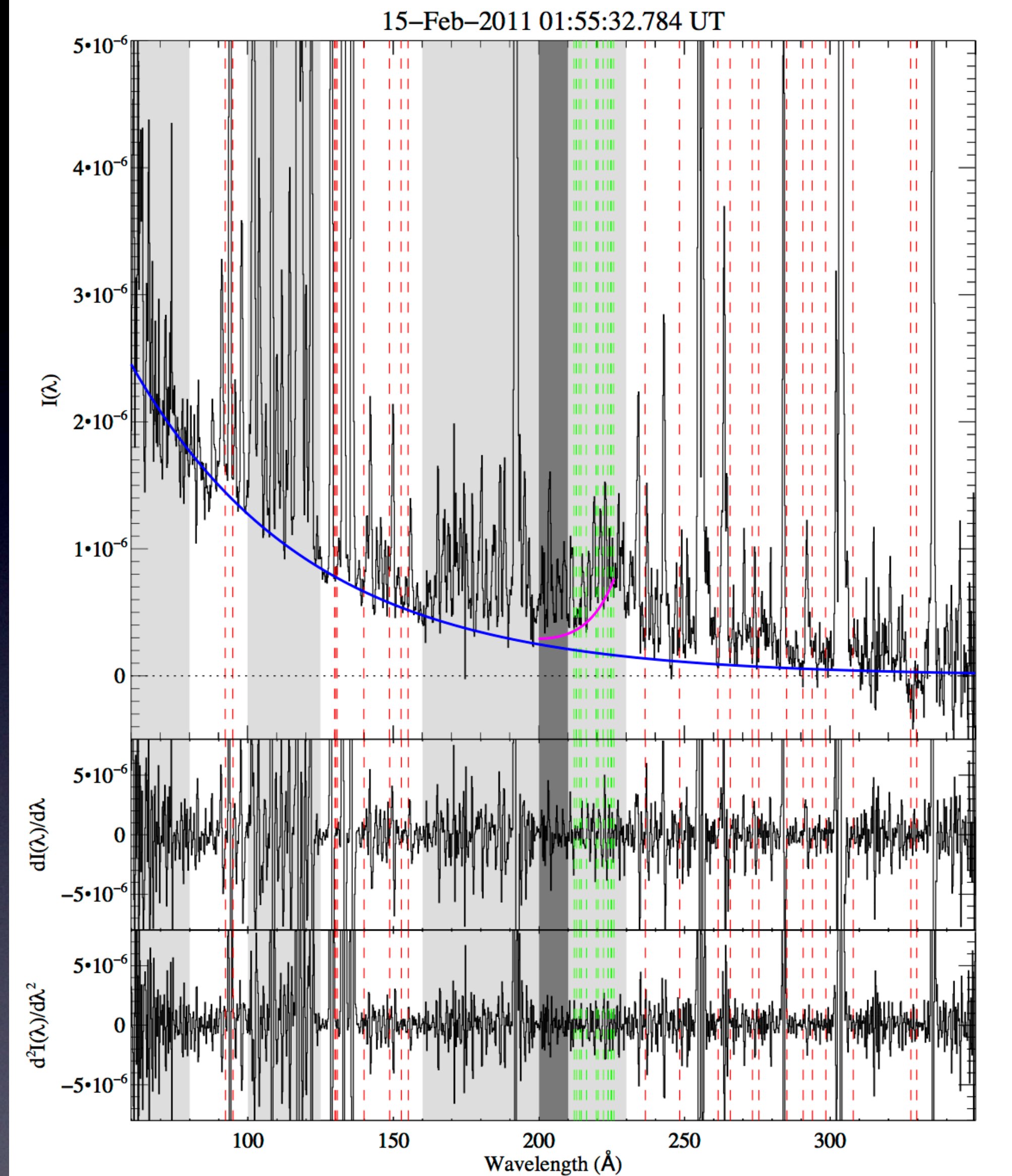


Figure 3: Example of how the local minima in the pre-flare subtracted EVE spectra were identified and fit in order to quantify the continuum

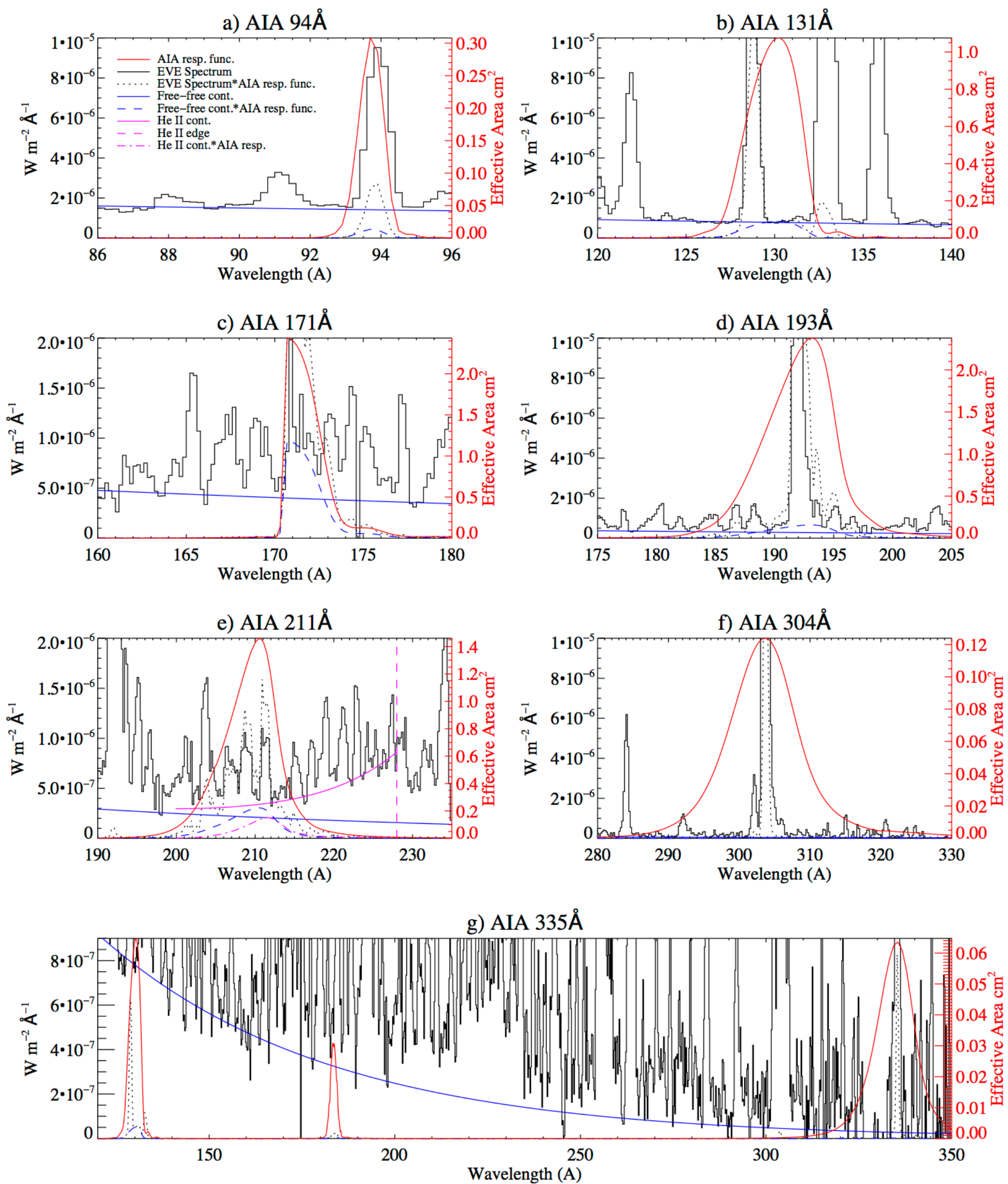


Figure 4: Convolution of the EVE spectra, and fits to the free-free continuum, with the AIA response functions

- In order to determine the continuum contribution to each passband throughout the flare, both the pre-flare subtracted EVE spectra (black histograms) and fits to the free-free continuum (solid blue curves) were convolved with each of the AIA response functions (solid red curves)
- This gave a measurement of the total emission (dotted black curve) and free-free emission (dashed blue curve) in each channel
- The total line emission was found by taking the difference of the two.
- In the case of the 211 Å channel, fits to the He II continuum (solid magenta curve) were also included

- This process was repeated for each 10s time step throughout the flare
- The relative amounts of line (red curves) and continuum emission (blue curves) could then be measured
- The lightcurves of the continuum emission were observed to peak around the SXR peak of the flare
- In the case of the 211Å channel, fits to the He II continuum were only included up to the GOES end time of the flare (purple curve, panel d)

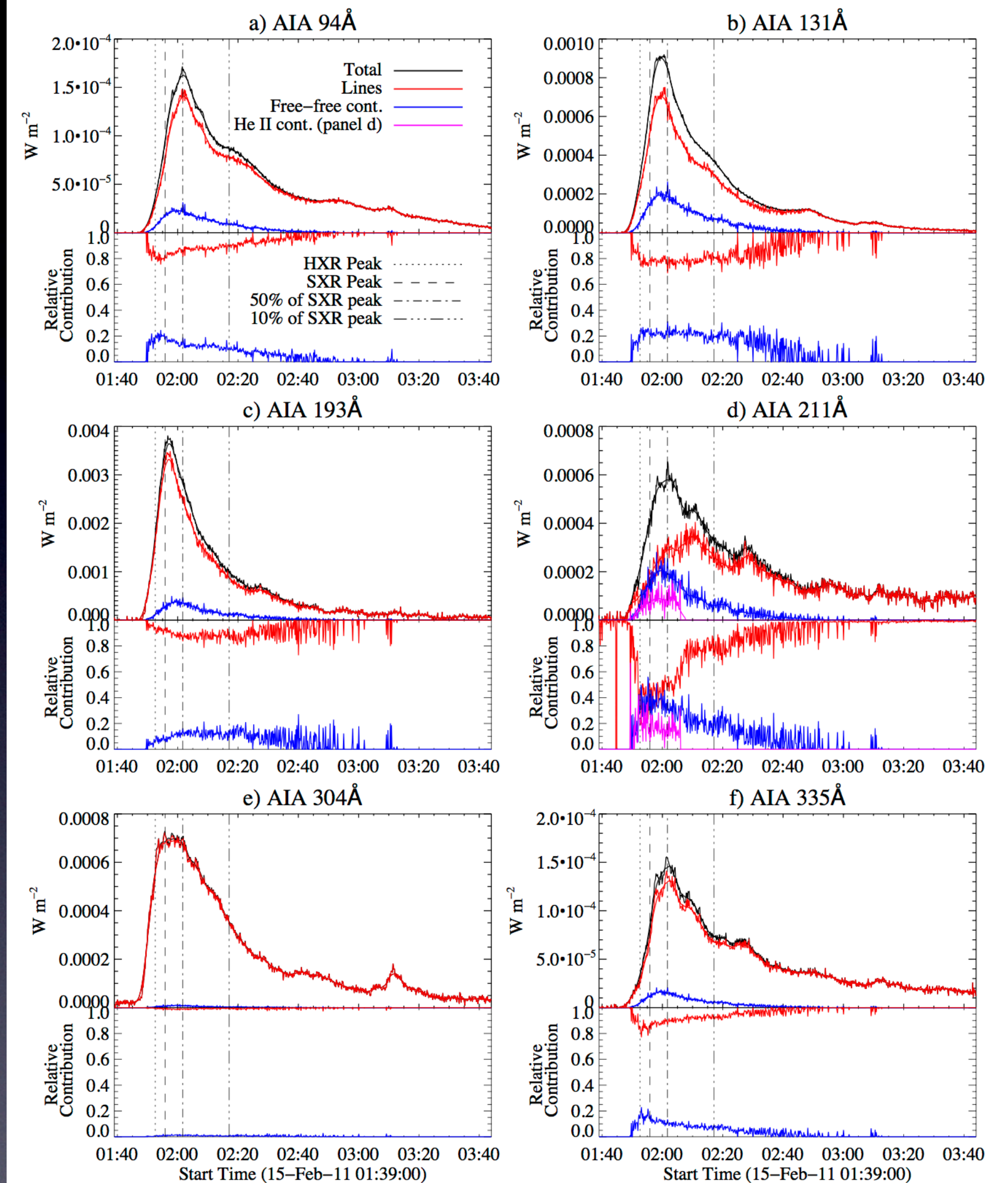


Figure 5: Lightcurves of the total (black) emission in each passband, along with the relative fractions of line (red) and continuum (blue) emission

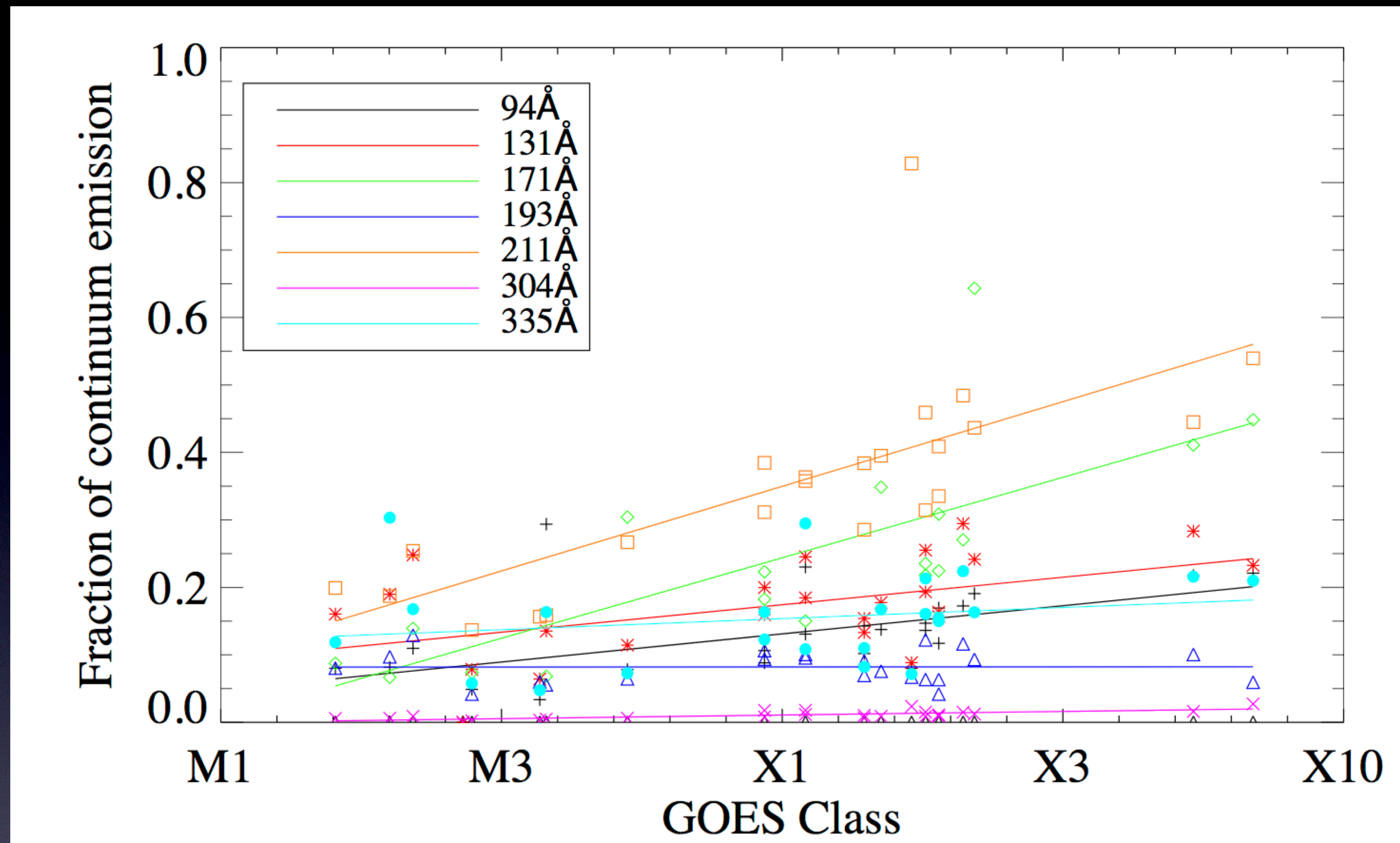
|      | HXR Peak | SXR Peak | 50% of SXR Peak | 10% of SXR Peak |
|------|----------|----------|-----------------|-----------------|
| 94Å  | 0.19     | 0.19     | 0.13            | 0.11            |
| 131Å | 0.21     | 0.24     | 0.23            | 0.22            |
| 171Å | -        | -        | -               | -               |
| 193Å | 0.08     | 0.09     | 0.13            | 0.15            |
| 211Å | 0.35     | 0.43     | 0.37            | 0.25            |
| 304Å | 0.01     | 0.01     | 0.01            | 0.01            |
| 335Å | 0.16     | 0.16     | 0.11            | 0.09            |

- The 94Å, 131Å, 193Å, and 335Å channels were each found to contain between 10-25% continuum emission during the main phase of the flare
- Results for the 171Å were inconclusive due to possible coronal dimming effects (see Woods et al. 2011)
- Continuum emission in the 304Å channel was found to be negligible
- The 211Å channel was found to contain the greatest amount of continuum emission (up to 50%) in agreement with O'Dwyer et al. 2010, who performed a similar analysis using CHIANTI spectra.

Table 1: The continuum contribution to each of the AIA channels at four times during the flare. The HXR peak was taken from the derivative of the GOES 1-8Å lightcurve.



Figure 6: The proportion of free-free continuum emission in each of the seven AIA channels over a range of M- and X-class flares, taken at their SXR peaks.



This analysis was repeated for a number of flares greater than GOES M2 class:

- The 193Å and 304Å channels did not show any dependance of continuum contribution on GOES class (<10%)
- The 94Å, 131Å, and 335Å channels showed a slight dependance on GOES class, ranging from 10-25%
- The 171Å and 211Å channels were found to exhibit a strong dependance on GOES class, to as much as 60%

# Summary

- We present a method for isolating the free-free continuum in SDO/EVE spectra during solar flares, and determining how much it contributes to the images in each of the AIA passbands
- For the 94Å, 131Å, 193Å, and 335Å channels, between 10-25% of the total emission can be due to free-free processes
- For the 211Å channel this can be as high as 60%, and was found to scale with respect to GOES class. There is also a significant contribution (~20%) from the recombination continuum of He II
- Continuum emission was found to be negligible for the 304Å channel, and difficult to ascertain for the 171Å channel due to possible coronal dimming effects during large events

# Conclusions

- The availability of EUV spectra from EVE that are concurrent with AIA images now allow the composition of emission in each channel to be determined
- Knowledge of which emission processes dominate the images under different conditions are crucial for interpreting the data correctly
- This is particularly relevant to studies that wish to use imaging data to determine plasma temperatures using filter ratios, or differential emission measures, during flares (e.g. Hannah & Kontar 2012, Battagila & Hannah 2012, Fletcher et al. 2013)

# Future work

A “red leak” was recently discovered in the 335Å passband. The leak spans the 600-800Å range (covered by the EVE MEGS-B channel) and may contain emission from the Lyman continuum, as well as myriad chromospheric and transition region lines. This is particularly significant during quiet Sun conditions, although not so much during flares.

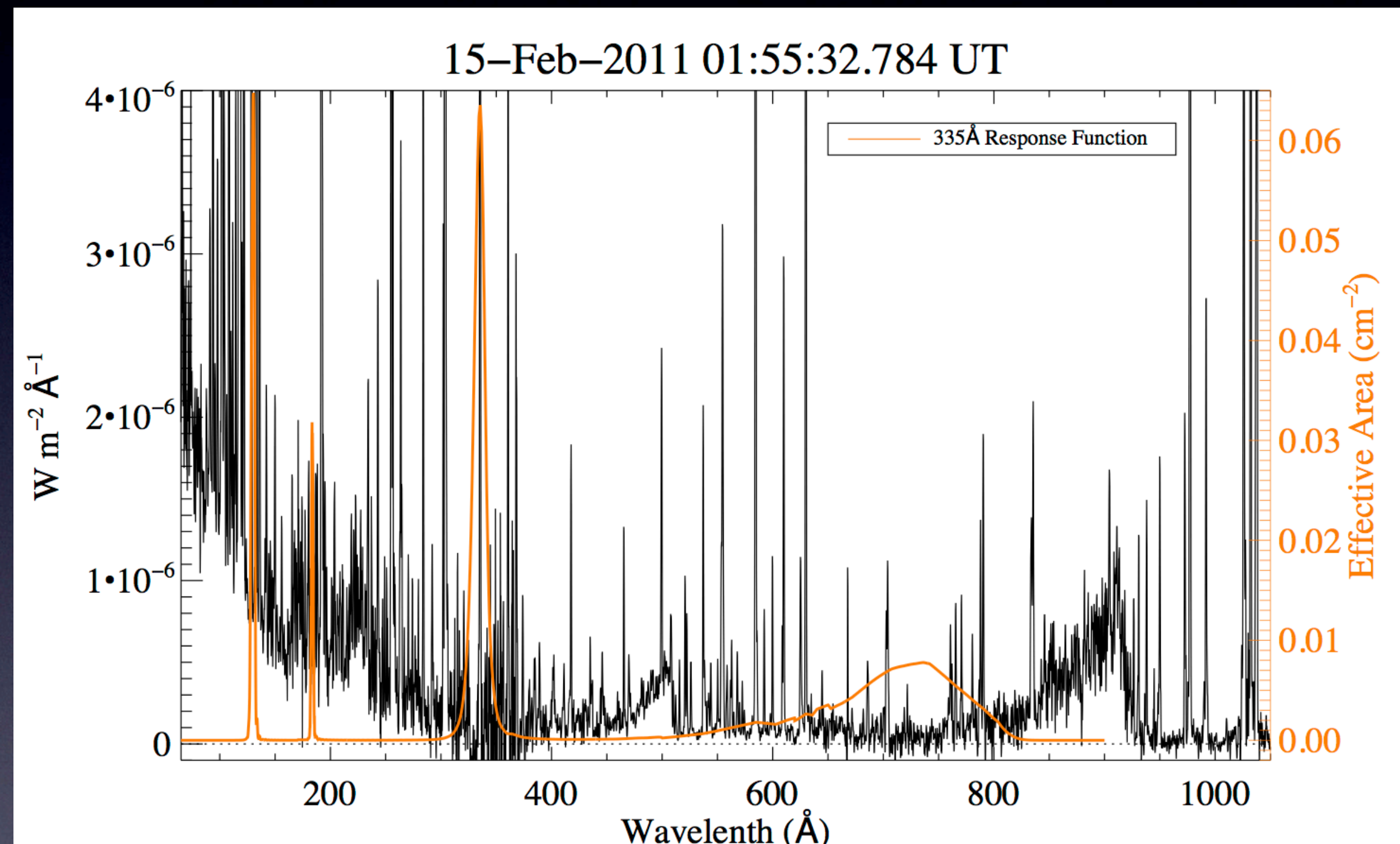


Figure 7: Combined spectrum from both MEGS-A and MEGS-B on EVE from the peak of an X-class flare. The latest version (April 2013) of the response function for the 335Å passband is overlaid in orange.