Pre-Impulsive Hard X-Ray Emission from Coronal Sources in X-Class Flares

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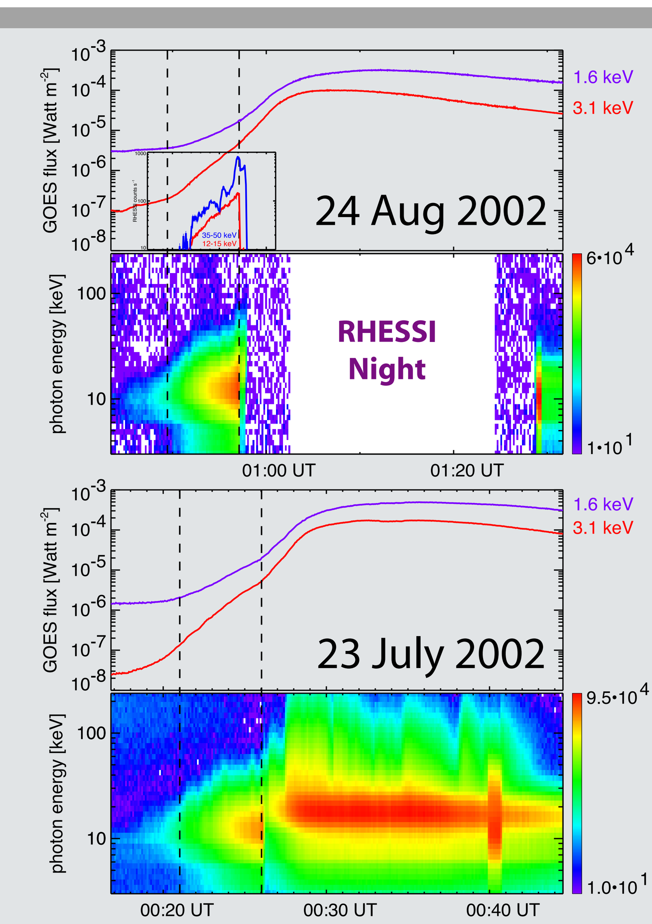
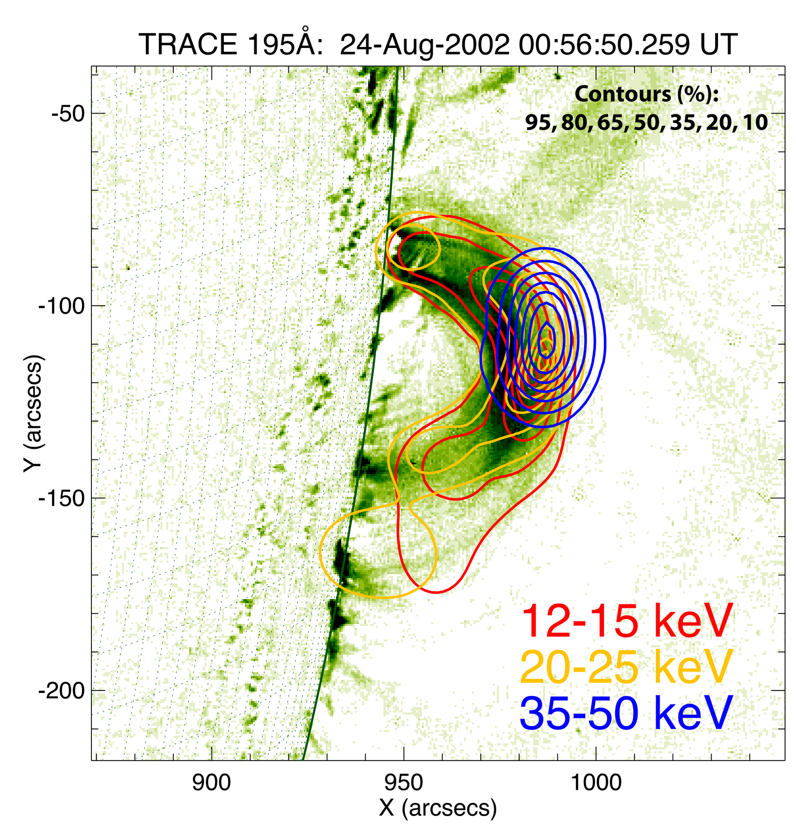
Summary:

The GOES-class X4.8 event on 23 July 2002 showed significant hard X-ray (HXR) emission prior to the impulsive phase of the flare (Holman *et al.* 2003). The X3.1 event on 24 Aug 2002 exhibits similar behavior and shares a similar time profile (see right). RHESSI images show that the HXR emission is from a coronal source. Spectroscopy suggests that this emission is non-thermal and may show thin-target bremsstrahlung emission above 35 keV.

A comparison with 23 July shows that the thermal and non-thermal emission behaves similarly in both flares. However, the footpoints for 23 July are not occulted and the photon spectra may indicate a true break in the injected electron energy spectrum.

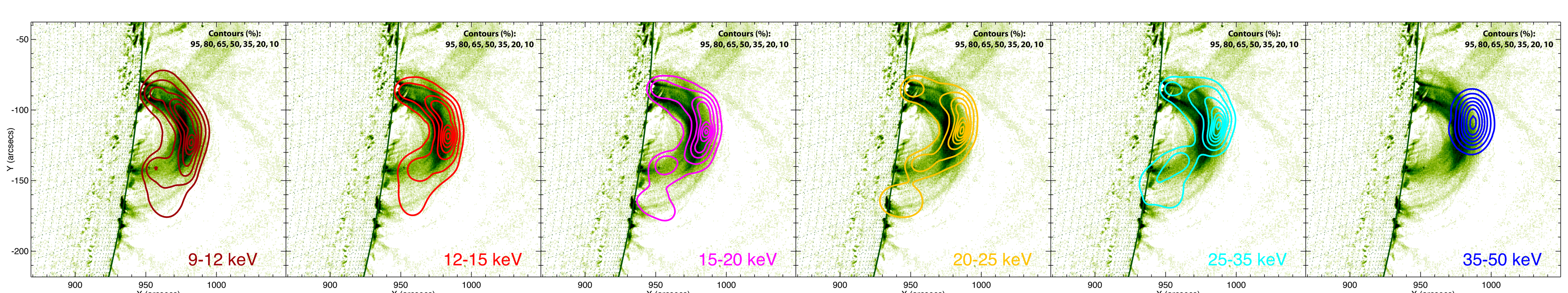
For both flares, the observations suggest continuous particle injection, requiring spectral inversion and a dynamical model utilizing a continuity equation to properly characterize the electron population as a function of time.





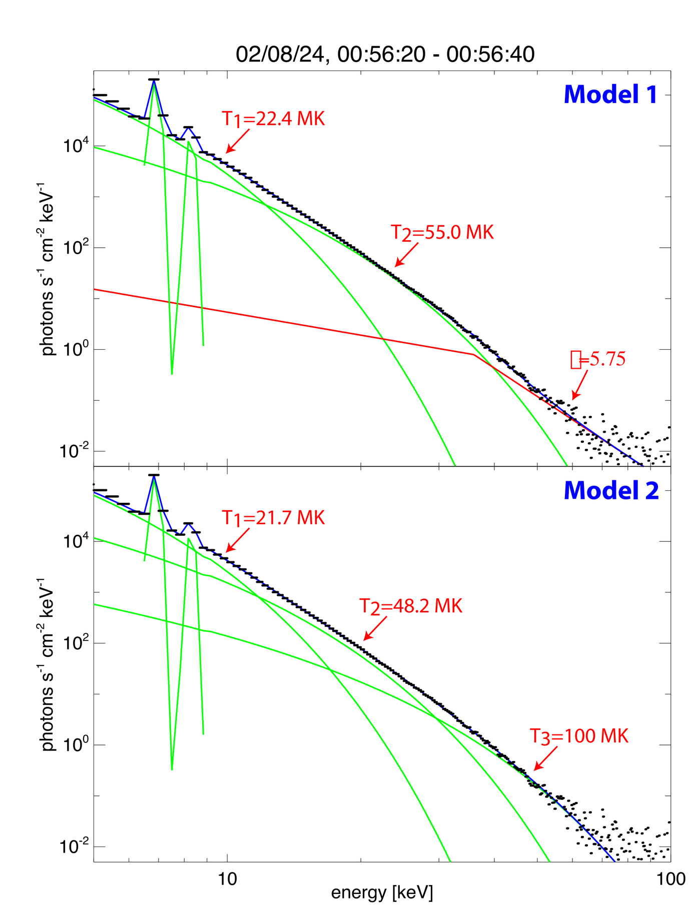
Imaging:

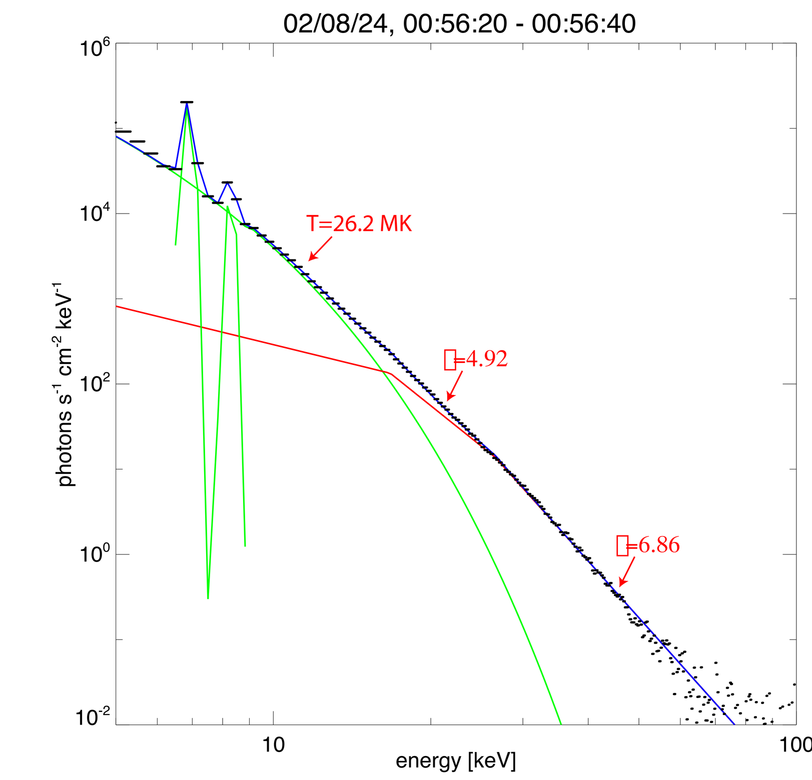
RHESSI X-ray contours from PIXON images are shown overlaid on a TRACE 195Å EUV image. The softer X-ray emission emanates from the entire loop, while higher energy emission is increasingly concentrated towards the looptop. The HXR source is unambiguously coronal, with X-rays >35 keV emitted solely from the looptop in a region ~1/5 of the total loop length. This suggests that >35 keV electrons are trapped at the looptop.



Possible spectral models:

The photon spectrum at the image time is shown with two model fits, both including two thermal components and adding a weak non-thermal component or a third thermal component. With no visible HXR footpoints, one might expect the HXR looptop emission to be primarily thermal. Both models yield reasonable fits employing superhot (>30 MK) thermal components. However, the >35 keV emission is bursty; if it is primarily thermal, the superhot plasmas must be able to heat and cool on short timescales, which may be unlikely for ~50-100 MK plasmas. Additionally, the Fe and Fe/Ni line complexes (at ~6.7 and ~8 keV) can be used to obtain constraints on the plasma temperature (Caspi & Lin 2006). Current understanding of the line emission yields plasma temperatures of ~20MK during the entire analyzed period, inconsistent with spectral models that require superhot components. The implication is that the HXR coronal source is, in fact, primarily non-thermal.



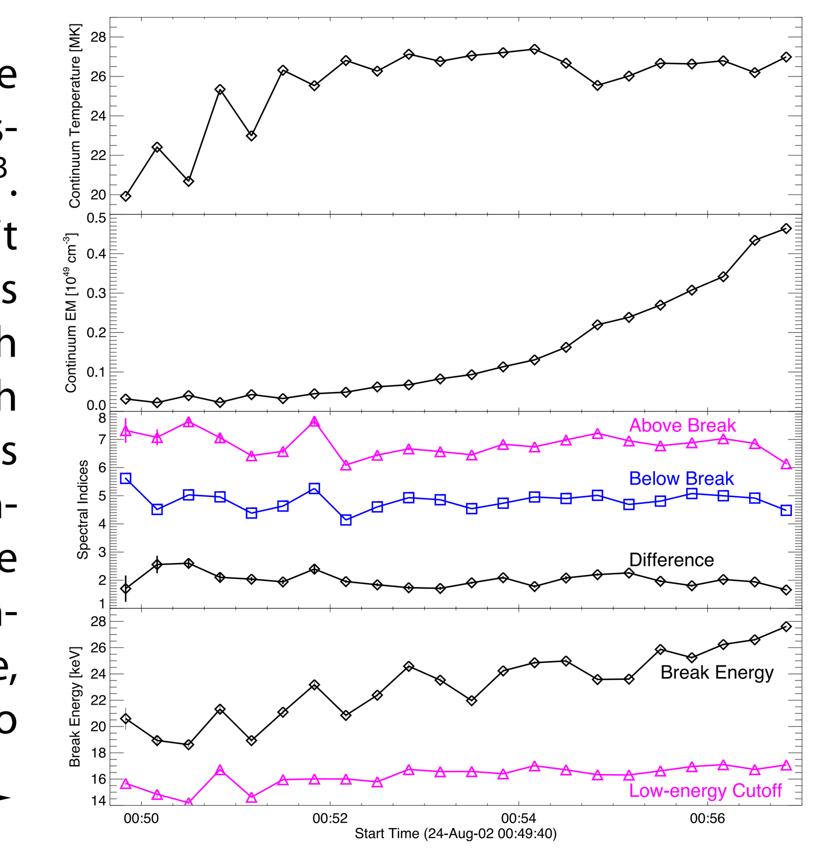


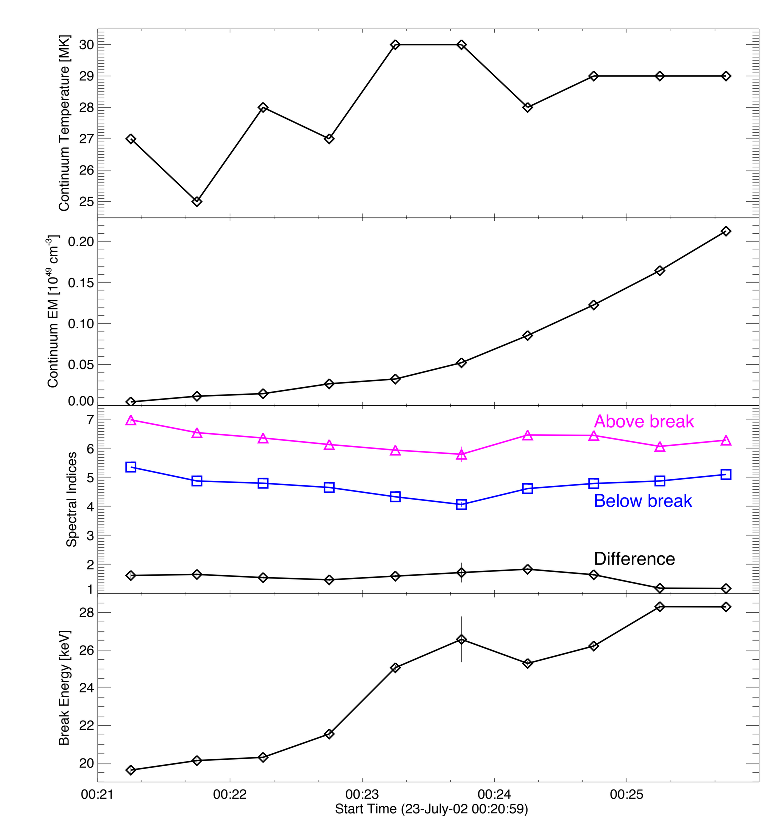
Spectral fitting:

Since the Fe & Fe/Ni lines suggest that the HXR coronal source is non-thermal, we perform a first-cut fit to the spectrum using a simple model consisting of a single thermal component and a non-thermal double power-law component. This model yields equally reasonable fits without requiring superhot temperatures. Since coronal densities are low, it is plausible that the emission from high-energy electrons >35 keV may be thin-target bremsstrahlung. Intriguingly, the power-law indices above and below the break energy differ by ~2, leading to the speculation that the break may be the transition energy between thin- and thick-target bremsstrahlung emission.

Spectral fit results for 24 Aug 2002, 20-sec intervals:

From the images, we estimate a loop half-length of ~3.5•10^9 cm and a volume of ~8•10^{26} cm^3, which are roughly constant during the flare. The rising emission measure suggests an increase in plasma density from ~10^{10} to ~10^{11} cm^{-3}. The inferred loop column density suggests that electrons >35 keV will emit thin-target bremsstrahlung. This emission should be visible from particles trapped in the looptop, while escaping >35 keV electrons will quickly reach the footpoints without losing energy (or emitting) in the loop, consistent with the imaging results. The difference of ~2 in the spectral indices also suggests thin-target emission from the coronal source (or a true break). However, non-thermal electrons will lose their energy with a characteristic collisional lifetime of <10 seconds at the inferred densities. We observe steady or increasing non-thermal emission at all times, implying a continuous particle injection. Hence, a population dynamics model without continuous injection is insufficient to fully and accurately describe the electron population.





Comparison with 23 July 2002, 30-sec intervals:

The pre-impulsive phase of 23 July 2002 behaves similarly to 24 Aug 2002. It is instructive to fit the same model and compare the results for both flares. As with 24 Aug 2002, the emission measure rises through the analyzed period, again suggesting a rising coronal density in the loop. Since the footpoints are not occulted, thin-target bremsstrahlung is not expected, thus the difference of ~1.5 in the spectral indices may suggest a convolution of thin- and thick-target emission or a true break in the injected electron energy spectrum. The steady or increasing non-thermal emission again implies continuous particle injection and thus to accurately describe the electron population, we again require a population dynamics model that accounts for continuous injection.

Preliminary Conclusions:

RHESSI images show that the HXR source on 24 Aug 2002 is unambiguously coronal, with no appreciable HXR emission from the region near the occulted footpoints. Imaging and spectroscopy suggest that the coronal source is non-thermal, and the spectra are consistent with thin-target bremsstrahlung from >35 keV electrons. This behavior is similar to that observed during the pre-impulsive phase of 23 July 2002, although in that flare the footpoints do show some HXR emission. In both cases, we observe continuous non-thermal emission despite a short collisional loss time for the energetic electrons, suggesting continuous particle injection and requiring application of a dynamical model with a continuity equation to describe the instantaneous energy spectrum of the electrons.

Future Work:

For both flares, we will apply the techniques of Johns & Lin (1992) and Lin & Johns (1993) to invert the photon spectra and apply a continuity equation to reproduce the electron energy spectrum as a function of time. We will also perform imaging spectroscopy to obtain separate spectra for the looptop source and for each loop leg.

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