RHESSI Observations of High-Temperature Plasmas in Solar Flares

Amir Caspi[1,2], Säm Krucker[1], R. P. Lin[1,2]

[1] Space Sciences Laboratory, University of California, Berkeley, CA 94720

[2] Department of Physics, University of California, Berkeley, CA 94720

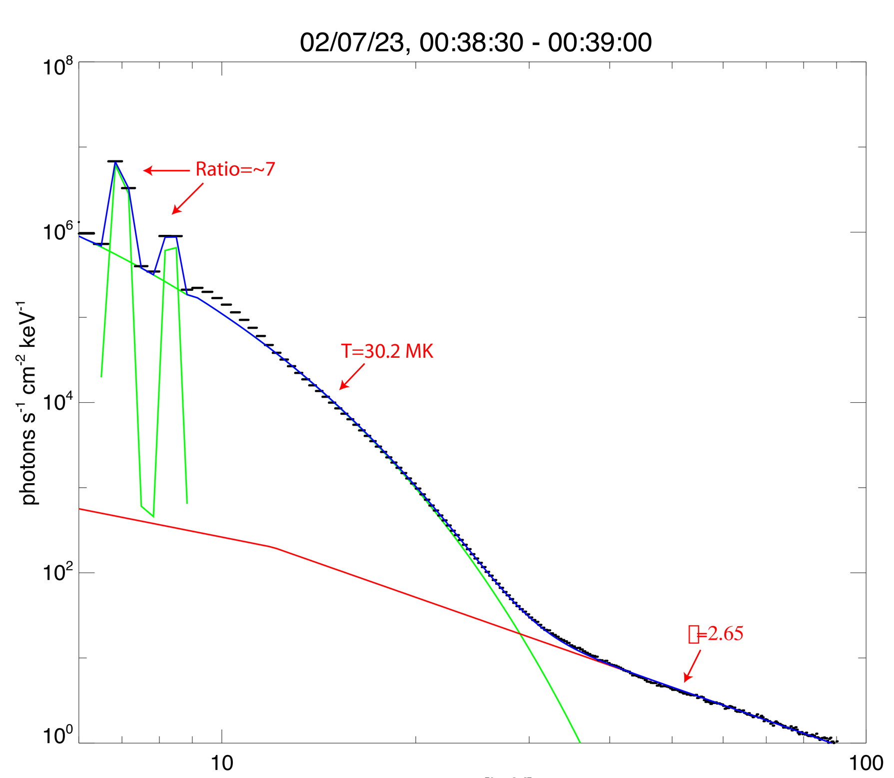
SH22A-0170

cepheid@ssl.berkeley.edu

http://sprg.ssl.berkeley.edu/~cepheid/agu2003/

Thermal continuum temperature and the Fe & Fe/Ni line complexes:

Solar flare plasmas are multi-thermal and may contain significant high-temperature components above ~20 MK. Emission at these temperatures includes the Fe and Fe/Ni line complexes at ~6.7 and ~8 keV. Phillips (2003) shows that the equivalent widths and fluxes of these line complexes are strongly temperature-dependent. This suggests that they may be good indicators of the hottest dominant flare plasma. We neglect any dependence on elemental abundances by considering only the ratio of the line fluxes. While widely-varying models may fit the spectral data equally well at times (see right), the Fe & Fe/Ni line complexes are strongly observed above the continuum in most flares, even with both attenuators in place (see below). Thus, the ratio of the line fluxes provides an independent diagnostic to constrain the temperature of the hottest dominant flare plasma, even in the absence of a reliable fit to the thermal continuum.

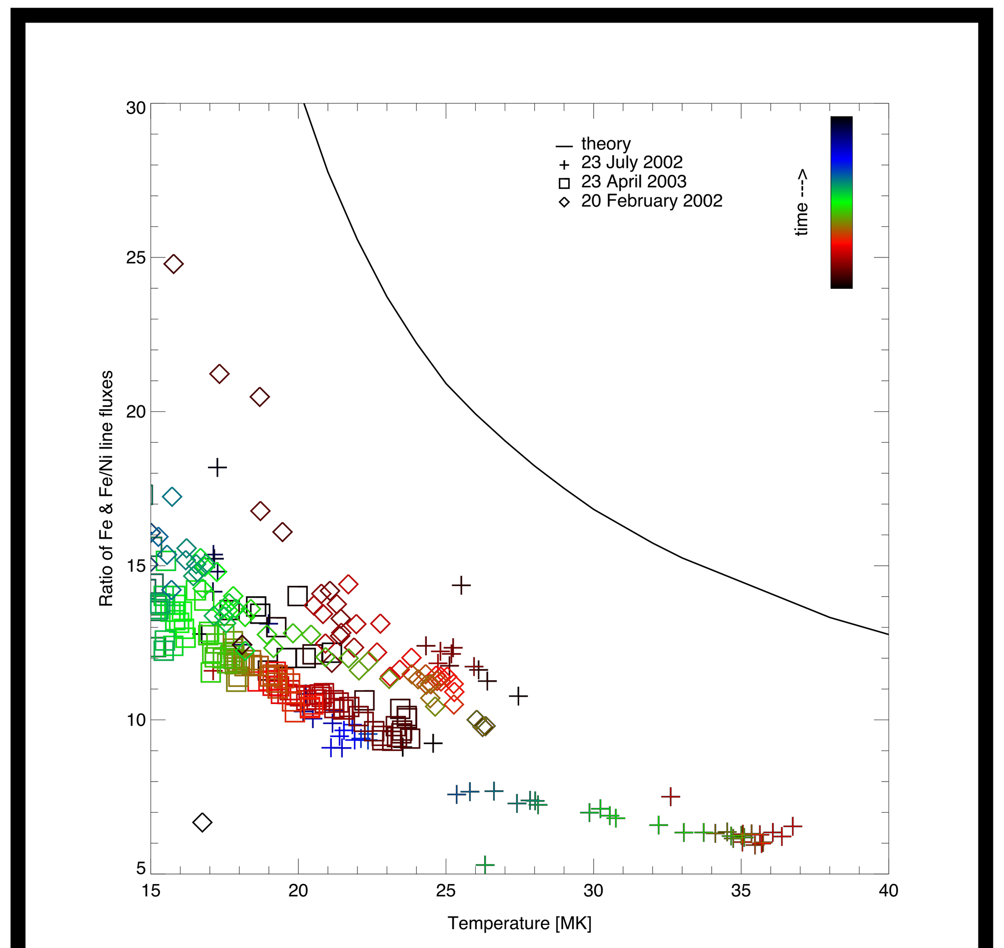


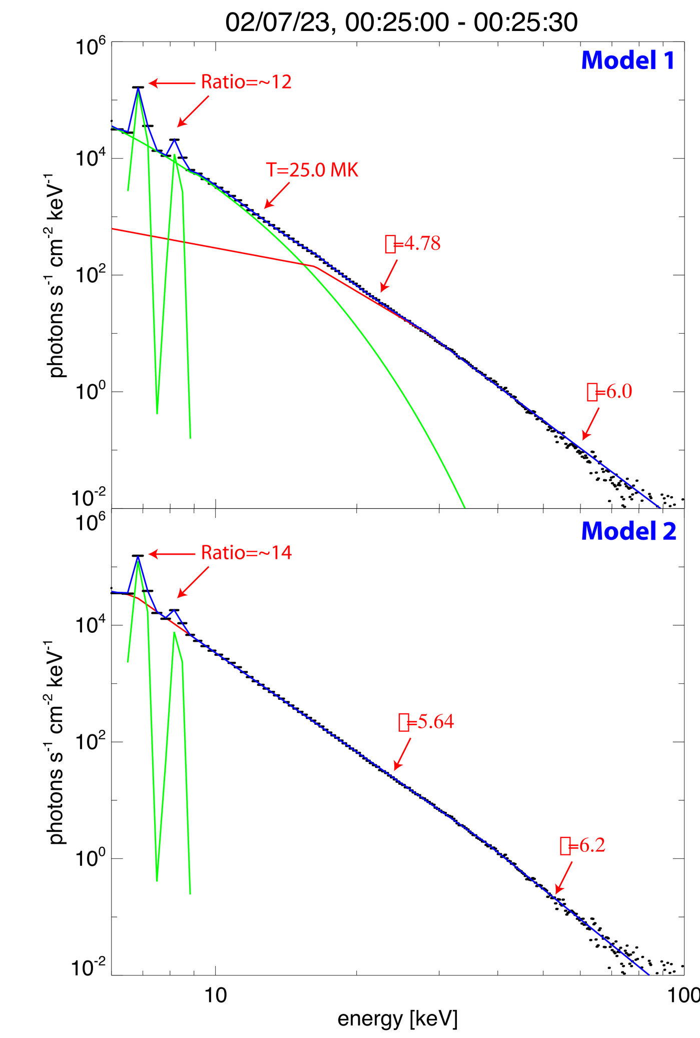
Spectral fitting:

Each flare was divided into time intervals of 12 or 30 seconds. For each time interval, we fit a single thermal component at low energies, a broken power law at high energies, and 2 Gaussians at the line complex centroid energies. We omitted times with high detector deadtime or poor statistics due to low count rate. The ratio of the line fluxes was calculated from the fit parameters and compared to the best-fit isothermal continuum temperature. The example spectrum at left is at the peak of the 23 July 2002 event, when both attenuators were in place. The Fe and Fe/Ni line complexes are clearly visible above the thermal continuum. The artifact at ~9 keV is likely due to count pileup.

Line flux ratio vs. temperature:

From the data obtained above, we plot the line flux ratio against the continuum temperature at each time interval, for each flare; the results are presented at right. Each transparency shows one flare, in order from back to front: 23 July 2002, 23 April 2003, and 20 February 2002. The theoretical prediction by Phillips (2003) is shown for comparison. For each flare we can see a clear relationship between the line flux ratio and the continuum temperature - the points define a correlation curve on each plot. Overlaying the plots, we observe a very good agreement in the curves for 23 July 2002 and 23 April 2003, suggesting that this empirical correlation curve may be common to many flares. The data for 20 February 2002 does not agree with the other flares, although there may be complications in the analysis (see discussion, right). It is significant that all of the data differs significantly from the theoretical prediction, although the reason for this is not yet known.



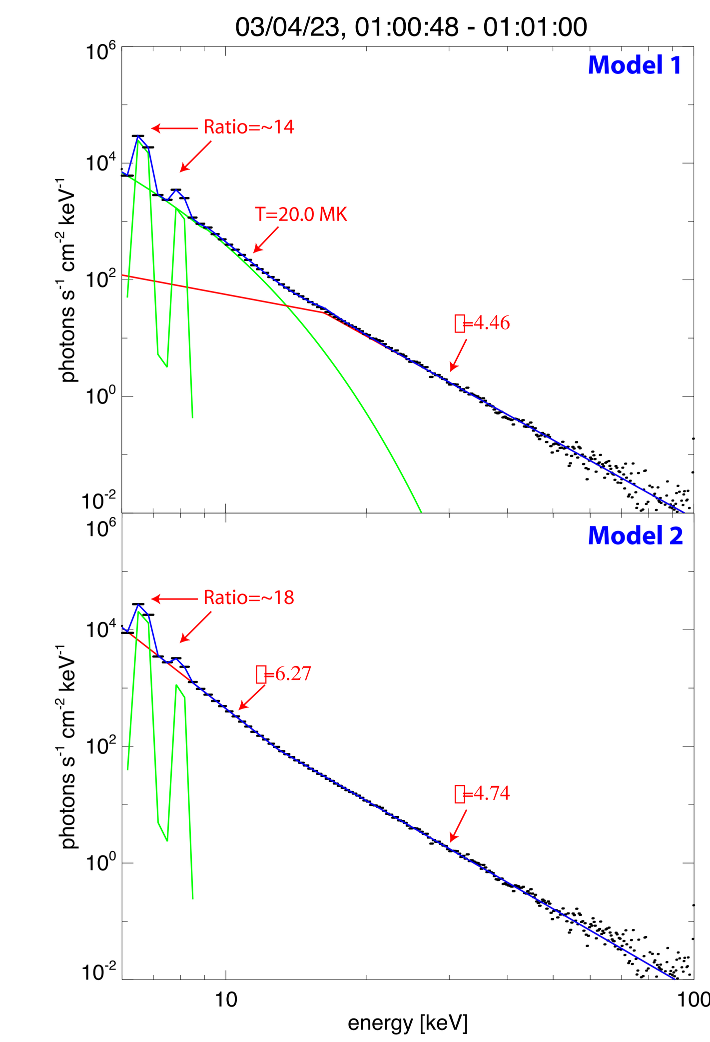


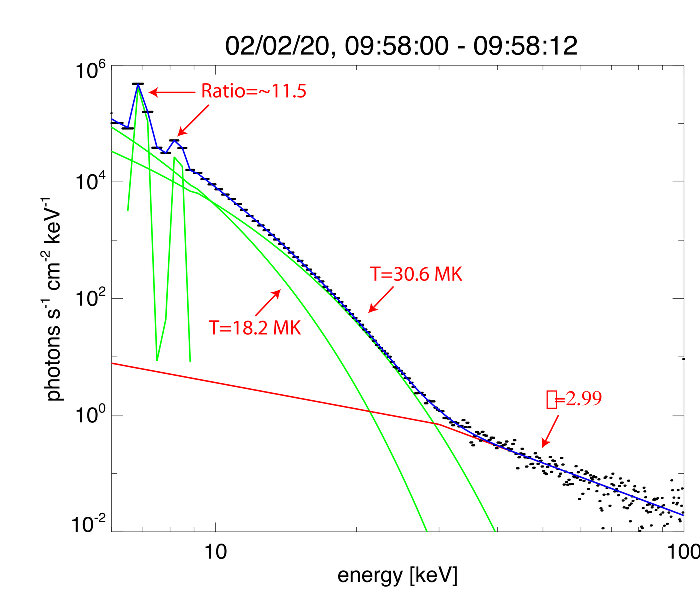
23 July 2002:

From the data (below, left), there is a clear correlation curve between the best-fit continuum temperature and the line flux ratio. The cluster of outliers (circled) is quite interesting, however. They occur during the pre-impulsive rise phase of the flare, where the spectral fits are rather ambiguous. Indeed, the spectral data is fit equally well **with or without** a thermal component, as shown by Holman et al. (2003) and by the example spectra at left. While we cannot infer the existence of a thermal component based solely on the spectrum above 10 keV (Lin et al. 2003), the Fe and Fe/Ni line complexes are well-defined and clearly indicate the existence of a thermal component. The line flux ratios suggest a continuum temperature of ~15 MK, significantly lower than the temperature given in the ambiguous fit at left. This implies that the thermal continuum during the pre-impulsive phase may be cooler than previously thought. Thus we see the strong diagnostic value of the line flux ratio as a constraint on the thermal parameters, even when they are not obvious from the spectral shape alone.

23 April 2003:

From the data, we can again see a correlation curve between the continuum temperature and the line flux ratio. Moreover, the transparency overlay (below, left) immediately suggests that this curve is identical to that from 23 July 2002. We again see a small cluster of outliers (circled) that, as before, occur during the pre-impulsive phase. As with 23 July 2002, the spectral data at this time is fit equally well with or without a thermal component, as shown at right. The line flux ratios indicate a thermal component at ~13 MK, significantly cooler than the fit value. Once again, the Fe and Fe/Ni line complexes provide a constraint that can help us analyze this intriguing pre-impulsive phase behavior. Additionally, the similarities between this event and 23 July 2002 suggest that our empirical correlation curve may be common to many flares. It may thus serve as a useful tool in understanding the evolution of high-temperature plasmas in a variety of flares.





20 February 2002:

The correlation curve for this flare does not agree with that for the other two flares. However, this flare is much better fit with 2 thermal components than with just one. Since the line emission is stimulated by both thermal components, it is unclear how much of the line flux (and therefore the flux ratio) is due to either thermal component. Thus the comparison between the line flux ratio and the isothermal continuum temperature is no longer well-defined. The agreement in the **shape** of the correlation curve is encouraging, and hints that a more detailed accounting of the line fluxes may yield the same correlation curve as the other two flares.

Preliminary Conclusions:

The Fe-to-Fe/Ni line flux ratio appears well-correlated with the continuum temperature above ~15 MK for all flares analyzed, with good agreement between the 23 July 2002 and 23 April 2003 events. However, the empirical correlation differs substantially from the theoretical prediction (Phillips 2003). The outlying data points off the empirical curve occur at "anomalous" times where multiple widely-varying models fit the spectral data equally well. The ratios at these points imply lower temperatures than obtained by fitting, providing a possible constraint for a more detailed future analysis.

Future Work:

For these and other flares, we will obtain model-independent estimates of the line flux ratio by fitting over only the 6-10 keV range, then fit the entire energy range using the ratio as a constraint. We will also investigate the significance of line excitation due to multiple thermal components and nonthermal electrons.

REFERENCES

Holman, G. D., Sui, L., Schwartz, R. A., & Emslie, A. G. 2003, ApJ, 595, L97

Lin, R. P., et al. 2003, ApJ, 595, L69

Phillips, K. J. H. 2003, ApJ, (submitted)