Current progress on MinXSS-RHESSI joint DEMs

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Motivation

- Observations (e.g., TRACE, SOHO/EIT, BCS [SMM & *Yohkoh*], SXT, XRT, AIA, EVE, RHESSI etc.) have shown that solar flares are multi-thermal, but no single instrument covers the full temperature range (up to 30 MK) observed.
- Use of MinXSS (http://lasp.colorado.edu/home/minxss) and RHESSI (http://hessi.ssl.berkeley.edu) allows the Differential Emission Measure (DEM) : DEM(T) = $d(n^2V)/dT$; T is temperature, n is plasma density, and V is volume.
- The combined data sources cover a large temperature range with overlap in the energy range from 5 to 10 keV.
- The hybrid forward-fit method was developed for EVE-RHESSI DEM calculations. (See Warren etal. 2013ApJ...770L..116W, Caspi etal. 2014ApJ...788L..31C , McTiernan etal. 2019ApJ...881L..161M.)
- The process uses CHIANTI V9 (http://www.chiantidatabase.org) and instrument responses to predict MinXSS and RHESSI counts simultaneously, minimizing $\chi 2$.
- The DEM is parameterized by 9 Gaussian functions in logT space, with fixed centers/widths and variable amplitudes. Fe-Ni Abundance (relative to sun_coronal) is now a fit parameter (made possible via R.Schwartz CHIANTI_KEV). RHESSI D3 is used; (DRM is multiplied by a factor of 0.75 to account for loss of efficiency. McTiernan etal. 2019AGUEMSH13D3427M).

Data Set:

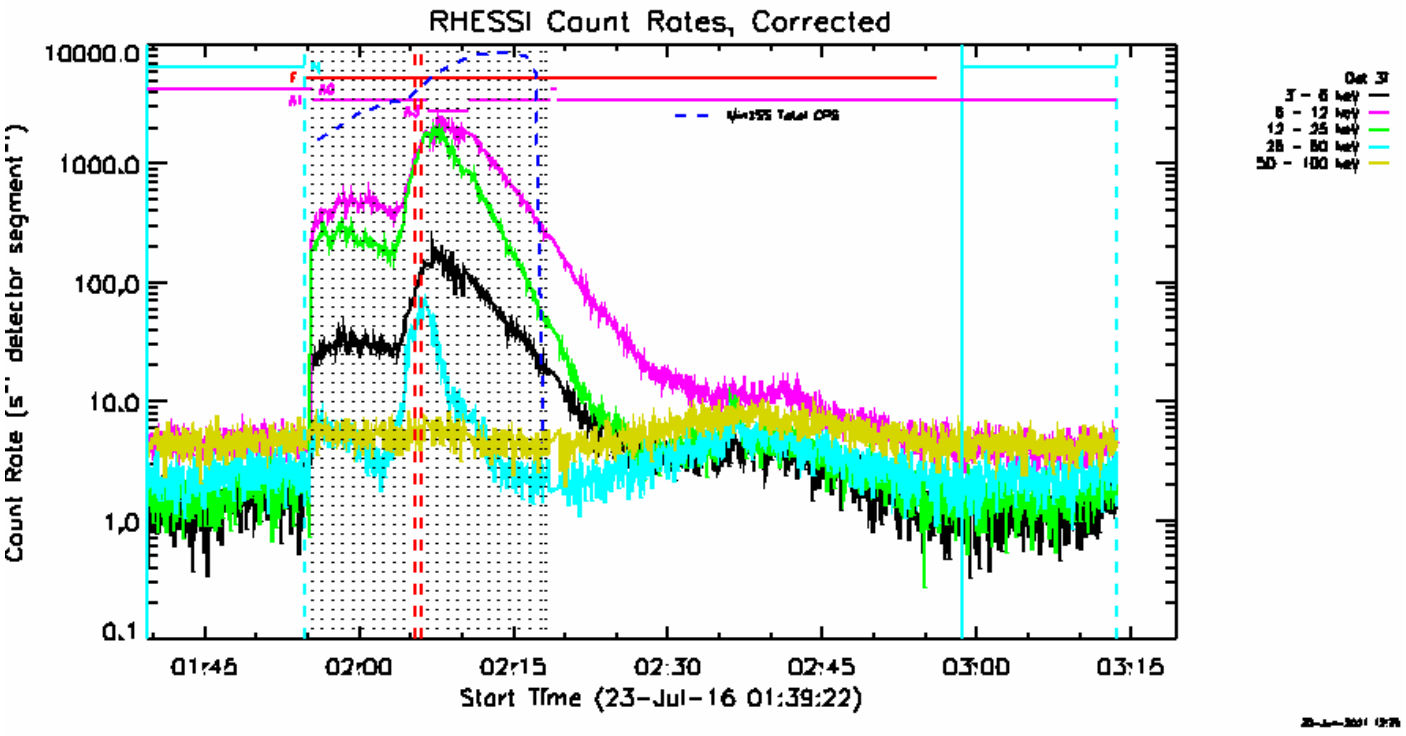
- 9 flare intervals observed by both MinXSS and RHESSI, from June 2016 through April 2017, GOES class C4++, 'good' (more than 20 MinXSS spectra) coverage.

RHESSI Start Time	RHESSI End Time	Number of MinXSS L1 Spectra	GOES Class	Fe Abundance (relative to solar_coronal)
2016-06-11 21:57:40	2016-06-11 22:17:28	115	C6.5	???+-???
2016-07-21 01:33:28	2016-07-21 01:37:32	24	M1.0*	???+-???
2016-07-21 01:40:00	2016-07-21 02:10:32	141	M1.0*	???+-???
2016-07-23 01:54:40	2016-07-23 02:34:52	165	M5.0	???+-???
2016-07-23 05:03:16	2016-07-23 05:26:32	66	M7.6	???+-???
2016-07-24 17:13:36	2016-07-24 17:50:28	139	M1.9	???+-???
2016-11-29 07:05:12	2016-11-29 07:21:08	92	C7.5	???+-???
2017-02-22 13:21:04	2017-02-22 13:34:04	74	C4.1	???+-???
2017-04-01 21:34:04	2017-04-01 22:21:28	50	M4.4	???+-???

- Used L0 MinXSS data (from http://lasp.colorado.edu/home/minxss), subtracted background, corrected for dead-time. We obtained an Ospex-compatible DRM (detector response matrix), from C. Moore.

Sample Calculation

- M5 flare from 23 July 2016, RHESSI count rates 3 to 50 keV:



- Dotted lines indicate ~1 minute intervals used for calculations, red dashed lines for interval used for plots in the next few slides. The blue dashed line shows the MinXSS total count rate. The RHESSI light curve looks as if there are two separate flares, with a new flare beginning at about 02:04 UT.

Results for DEM and Spectra

This figure shows results for 1 time Interval from 01:05:24 to 01:06:00 On 23 July 2016.

Top left: MinXSS counts spectrum, pink is observed, black is the model. Only data > 1 keV are included.

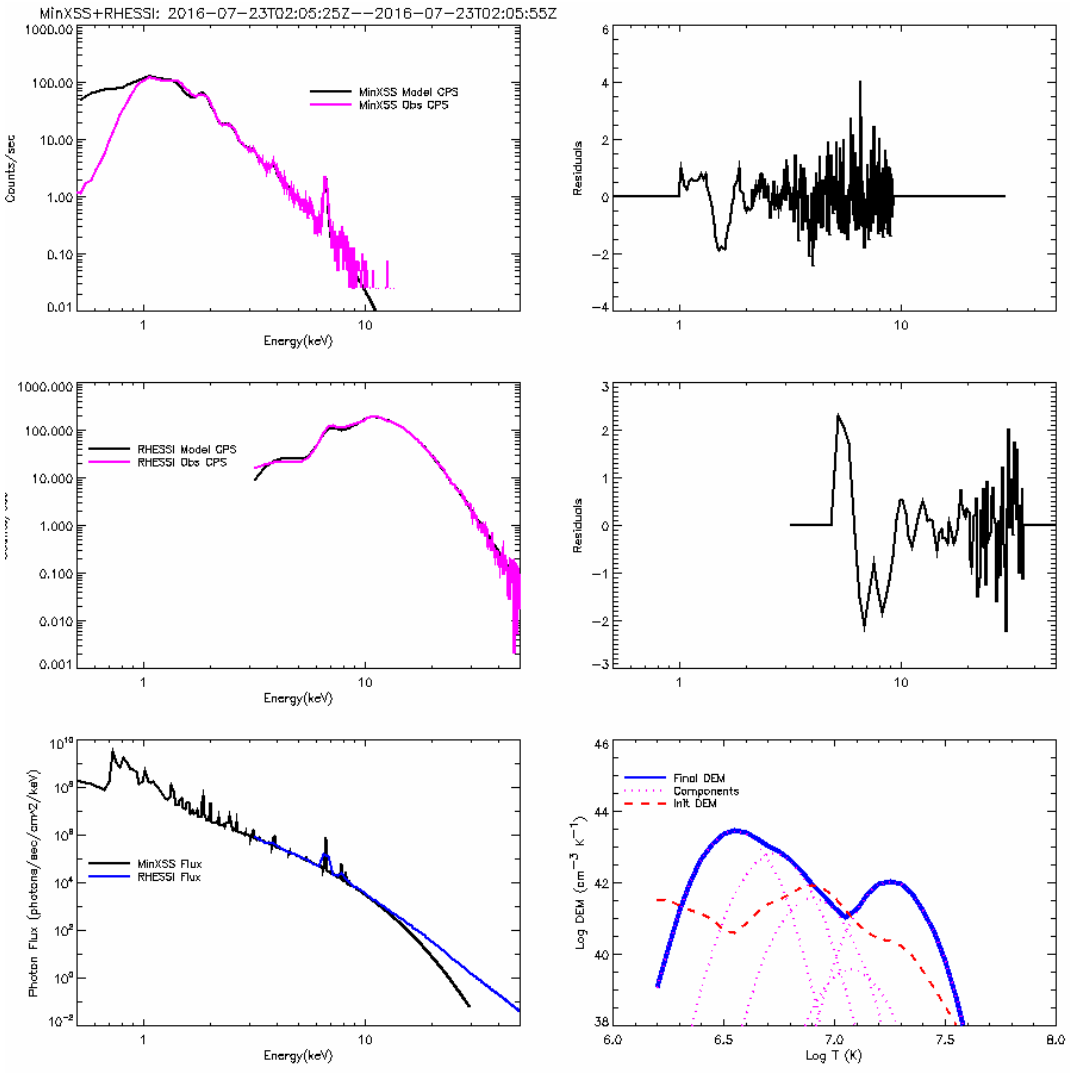
Top right: MinXSS residuals.

Middle left: RHESSI counts spectrum.

Middle right: RHESSI residuals.

Bottom left: Photon flux; black is MinXSS, blue is RHESSI (includes non-thermal with cutoff of 15 keV).

Bottom right: Recovered DEM. Pink dotted lines show individual components, red dashed line is initial guess.



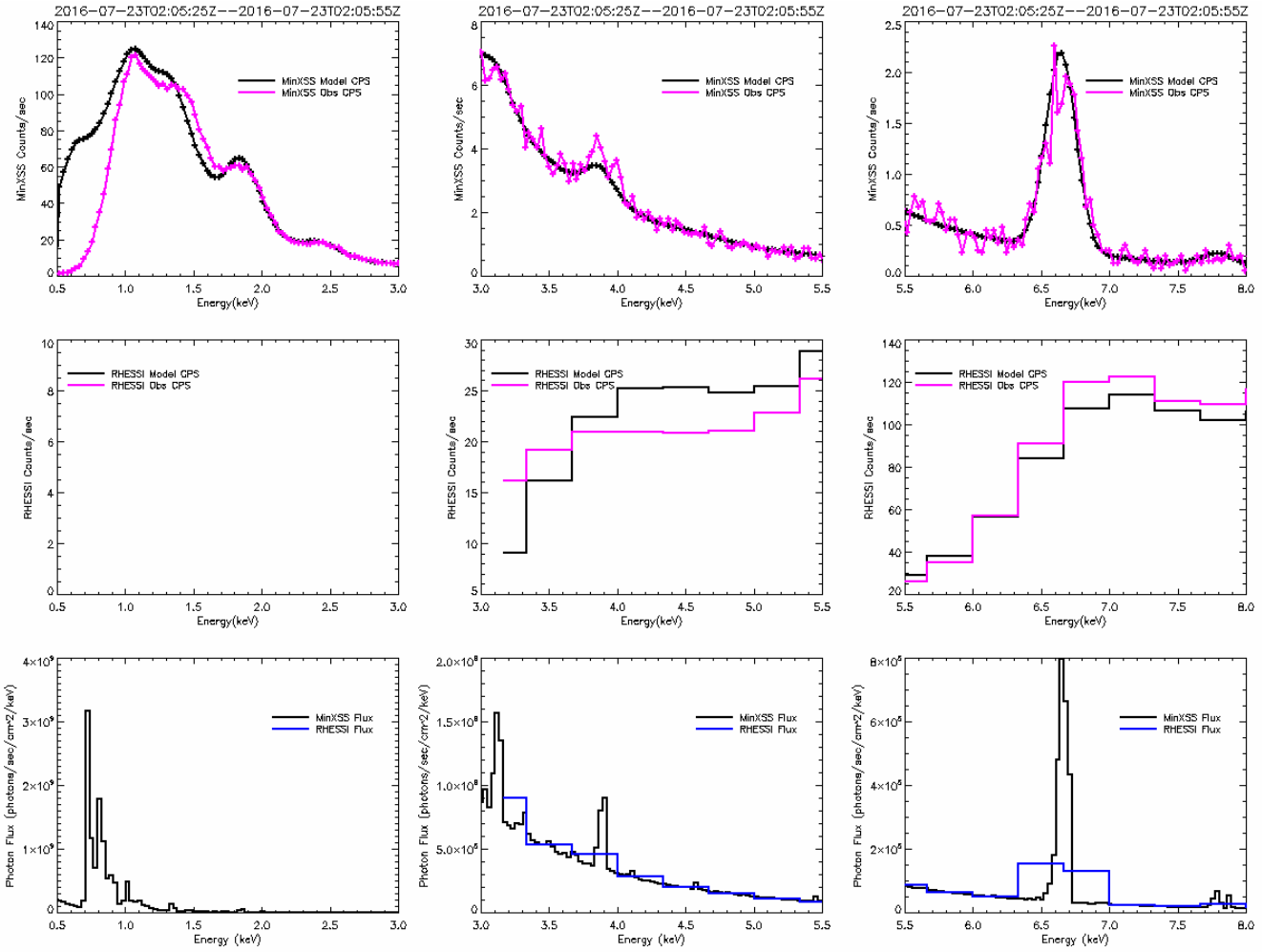
A closer look at lines:

This figure shows model-observation comparisons In 3 energy ranges for MinXSS and RHESSI, Between 0.5 and 8 keV.

Top: MinXSS spectra, pink is observed, black is model.

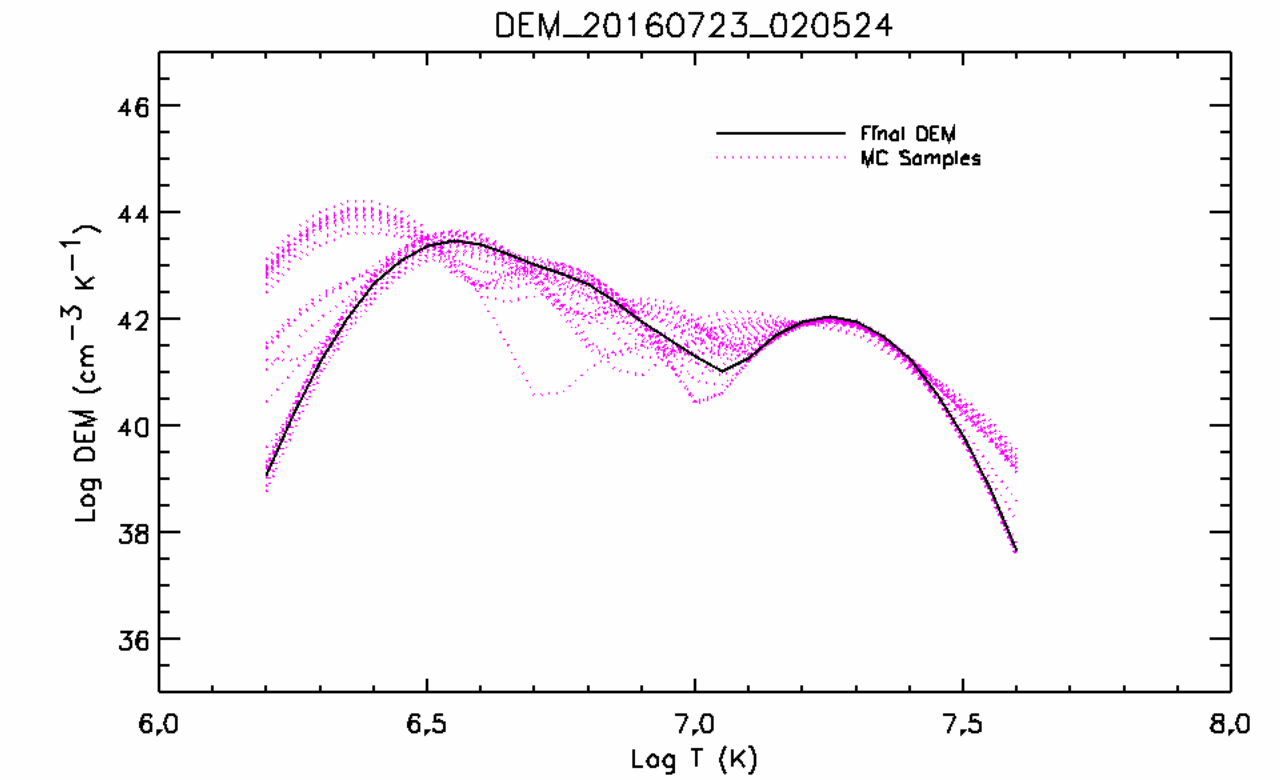
Middle: RHESSI spectra, only data > 5 keV is included in fit.

Bottom: Photon flux, Black is MinXSS, blue is RHESSI.



Uncertainties?

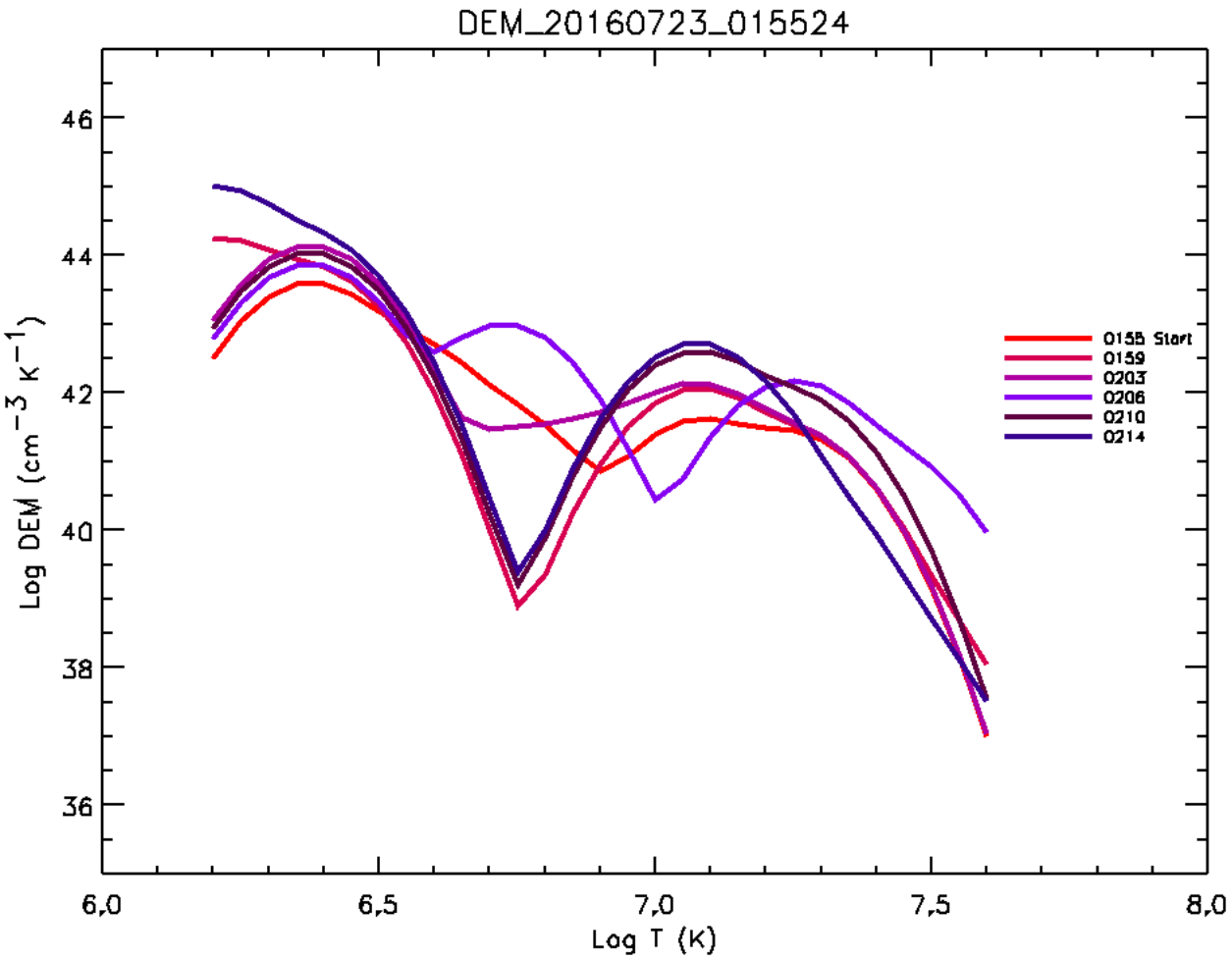
Uncertainties are estimated using a Monte Carlo technique. For each trial, the count rates in all MinXSS and RHESSI channels are varied using the Poisson distribution. Initial guesses are also randomized. The results are shown in this figure.



The black line is the recovered DEM for the 'true' observed data. The pink dotted lines show the results for the DEM for the different MC trials, which give an estimate of uncertainty at each temperature. Some temperature ranges are more uncertain (Log(T) < 6.5 and Log(T) around 7.0). Here, the uncertainty discourages interpretation of the result as a "two-temperature" distribution.

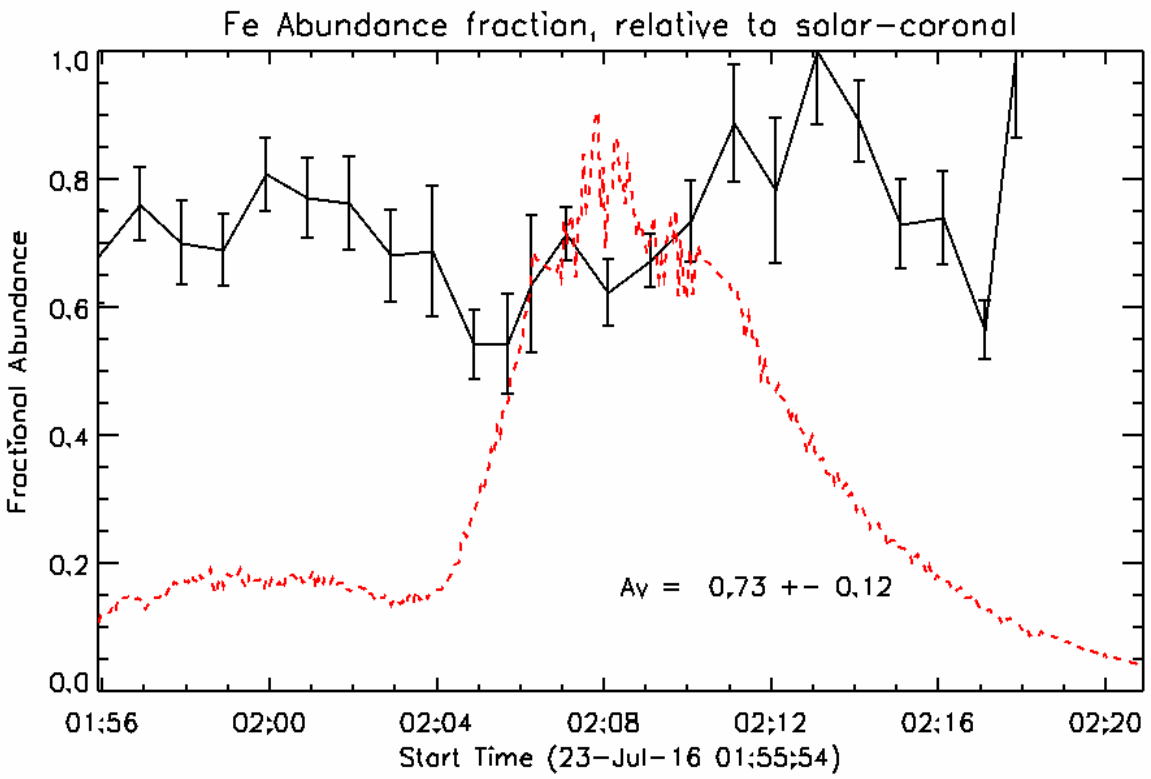
Time variation:

This figure shows some time variation of the DEM. The color values vary from red through purple to blue during the flare. The highest T emission occurs near the peak of the RHESSI SXR emission (purple, 02:06 UT). As far as we can tell from our small sample, this is only ‘typical’ type of time variation.



Relative Fe abundance variation:

This figure shows the time variation of the Fe abundance, relative to solar 'coronal' abundance. ('Photospheric' abundance would be a value of 0.25). There are some trends, but the error bars are large. The average value is 0.73 ± 0.12. The red dashed line is the RHESSI 6-12 keV count rate.



At about 02:04, which looks to be the start of a new X-ray burst, the abundance decreases slightly, then increases as the flare continues. Similar behavior is seen in the M7.6 flare that occurred later during 23 July 2016, but not in any of the other flares analyzed.

Abundance Values:

- Here is our table with the calculated abundances filled in. Except for the two M-class flares on 23 July 2016, the relative abundance is 0.51 or less. There looks to be a rough correlation between abundance and flare GOES class, with larger flares resulting in higher abundance, but the error bars are large and the sample size is small.

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2016-07-21 01:33:28	2016-07-21 01:37:32	24	M1.0*	0.43+-0.02
2016-07-21 01:40:00	2016-07-21 02:10:32	141	M1.0*	0.51+-0.07
2016-07-23 01:54:40	2016-07-23 02:34:52	165	M5.0	0.73+-0.12
2016-07-23 05:03:16	2016-07-23 05:26:32	66	M7.6	0.77+-0.14
2016-07-24 17:13:36	2016-07-24 17:50:28	139	M1.9	0.45+-0.08
2016-11-29 07:05:12	2016-11-29 07:21:08	92	C7.5	0.48+-0.12
2017-02-22 13:21:04	2017-02-22 13:34:04	74	C4.1	0.32+-0.04
2017-04-01 21:34:04	2017-04-01 22:21:28	50	M4.4	0.49+-0.17

Conclusions:

- DEMs:
- Combined MinXSS, RHESSI DEM models fit data pretty well, for MinXSS data > 1 keV and RHESSI data > 5 keV.
- Uncertainties obtained via Monte Carlo estimates tend to be large in some temperature ranges, making it difficult to divide the DEM into components.
- Typically, the highest temperature emission is associated with times near the RHESSI SXR peak.
- Abundances:
- There is some trending in Fe abundance measurements in the time variation for the 2 largest flares, with lower abundance corresponding to higher SXR emission. Error bars are large, though.
- The observed relative abundances of 0.3 to 0.8 to solar coronal may be the combined effects of FIP and inverse-FIP fractionation. (See Laming 2021ApJ...909L...17L.)

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