eHeroes activity

Multitemperature solar plasma diagnostics from RESIK spectra

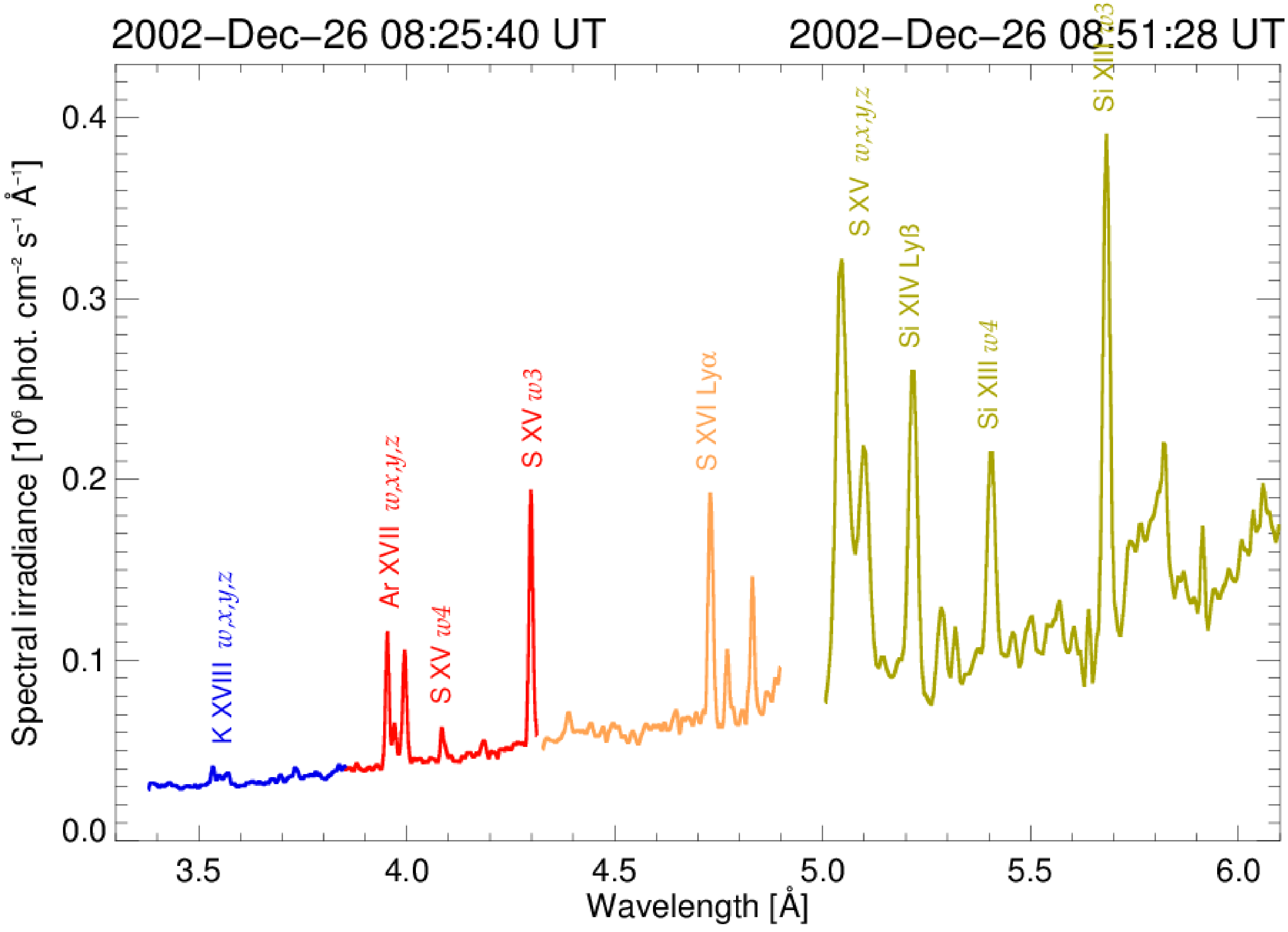
B. Sylwester, A. Kępa , J. Sylwester
Space Research Centre, PAS, Wrocław, Poland
K.J.H. Phillips
Mullard Space Science Laboratory, Dorking, UK

RESIK

We present the results of differential emission measure (DEM) analysis of flaring plasma. The analysis is based on the X-ray spectra obtained with Polish-led spectrometer RESIK on Russian *CORONAS-F* satellite. RESIK is the **uncollimated** bent crystal spectrometer consisting of two double-channel X-ray spectrometers.

It was designed to observe solar coronal plasmas in four energy bands. The nominal wavelength coverage of RESIK is **3.3 Å – 6.1 Å**. Recorded spectra contain many spectral lines formed in H- and He-like ions of various elements. The line and continuum is formed in hot coronal plasma from the T-range **3 MK ÷ 30 MK** in various proportions for different spectral bands. This makes RESIK spectra uniquely suitable for investigations of the temperature structure of the source (**DEM**) as well as the plasma **elemental composition**.

Time-averaged RESIK spectrum for an C1.9 flare



The Differential Emission Measure (**DEM**)

For optically thin, mulithermal plasma:

$$F_i = A_i \int_{T=0}^{\infty} f_i(T)\phi(T)\,\mathrm{d}T$$

DEM characterizes the amount of plasma at various temperatures present in the source.

$$\text{DEM} \equiv \Phi(T) \equiv Ne^2 \frac{dV}{dT}$$

is non-negative

F_i → measured fluxes obtained from RESIK spectra in *i* =15 spectral bands

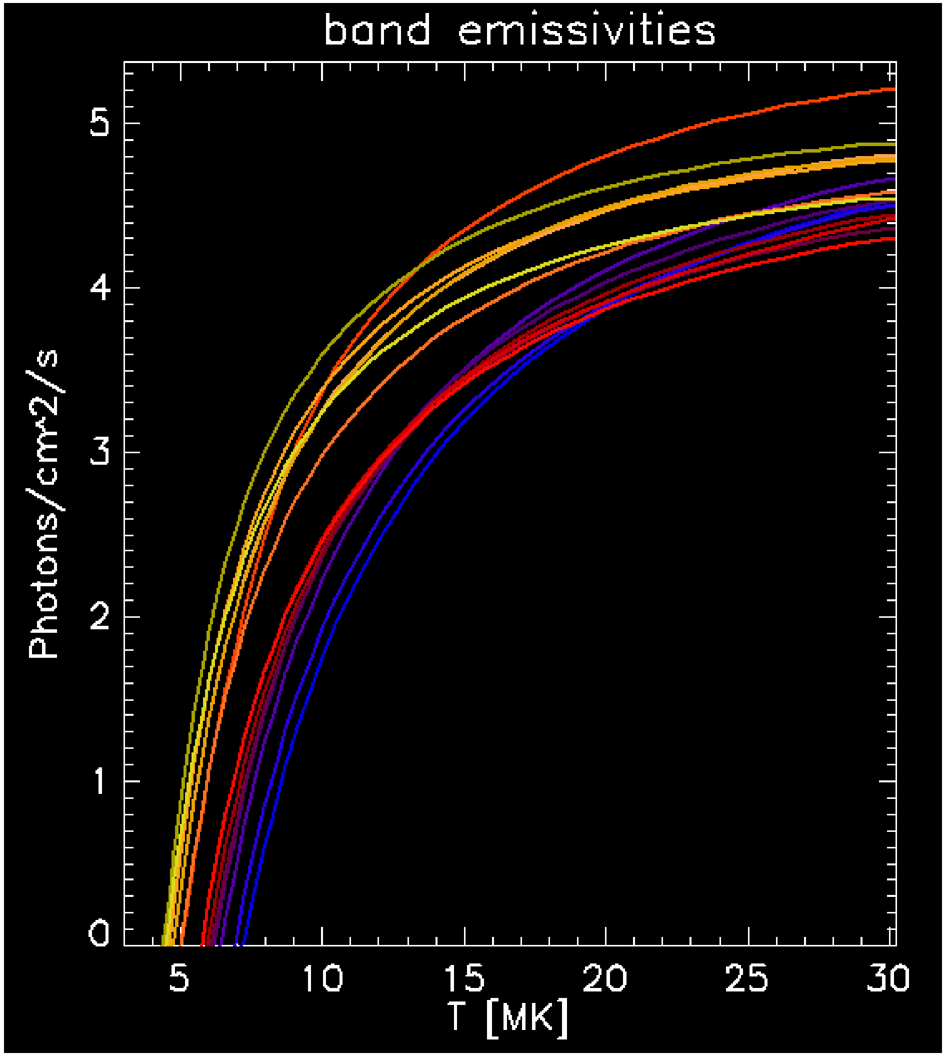
$f_i(T)$ → calculable theoretical emission functions for every spectral band used, CHIANTI 7.0 atomic code has been used in this respect

A_i → assumed elemental abundance taken as constant over the source volume

DEM inversion

From reduced absolute RESIK spectra we have selected 15 narrow spectral bands embracing the most intense lines and the continuum below. We determined the time-changing fluxes in these bands for flares selected in this research. These fluxes constitute the input set for the differential emission measure (DEM) inversion $F_i \rightarrow \Phi(T)$.
The theoretical fluxes have been calculated using the CHIANTI 7.0 code (http://www.chiantidatabase.org) with appropriately selected plasma composition – representative (optimum) for each selected event for the elements: Ar, S, Si, and adopting coronal values (following Feldman, 1992) for other elements, except for K and Cl, for which RESIK values were used (last slide of previous talk). In the spectral calculations, the ionization equilibrium of Bryans, Landi & Savin (ApJ, 691, 2009) has been adopted.
For the inversion, the Withbroe-Sylwester **iterative** algorithm representing the **maximum likelihood** approach (Solar Phys., 67, 1980) has been used.
The inversions have been carried out over the temperature range
3 MK - 30 MK. 10 000 iterations were performed on each inversion run in the accelerated scenario. The inversion uncertainties were determined from 100 Monte Carlo exercises, where the input fluxes for time-frame of interest were randomly perturbed with corresponding measurement uncertainties.

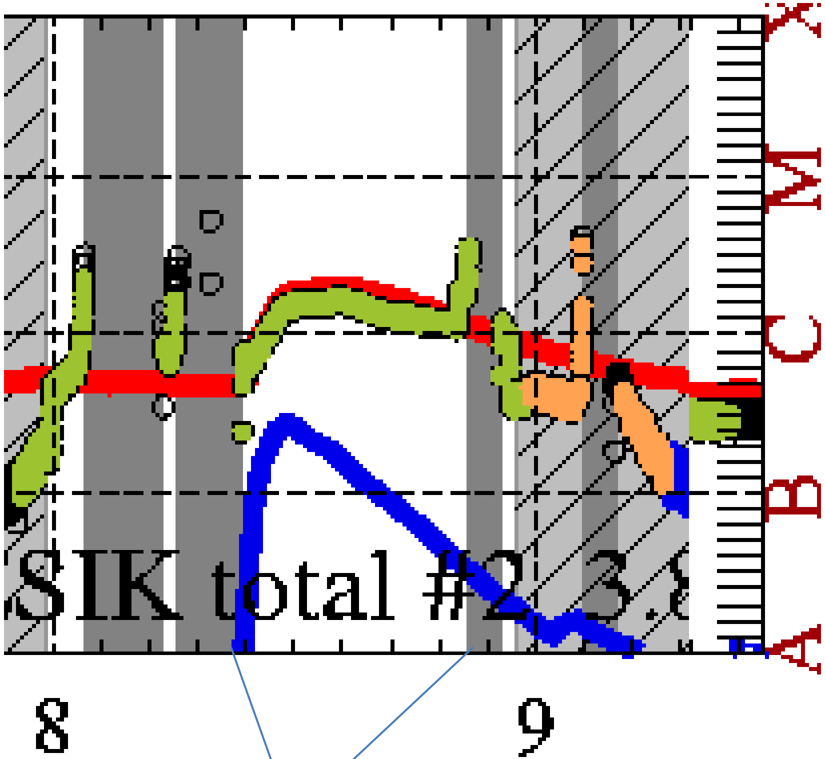
The emission (contribution) functions



Δλ [Å]		
3.40	3.62	K XVIII triplet ch #1
3.62	3.80	Ar XIII Lyα ch #1
3.90	4.07	Ar XVII triplet ch #2
4.11	4.25	S XV $1s^2$-1s4p + satellites ch #2
4.35	4.43	SXIV 3p satellites
4.43	4.52	Cl XVI $1s^2$-1s2p triplet + satellites
4.68	4.75	SXVI 1s-3p Lyα
4.74	4.80	Si XIV 1s-5p Lyδ
5.00	5.15	S XV $1s^2$-1s2p triplet + satellites
5.25	5.34	Si XIII $1s^2$-1s5p
5.34	5.48	Si XIII $1s^2$-1s4p+ 5p sat
5.48	5.62	Si XII 4p satellites
5.64	5.71	Si XIII $1s^2$-1s3p
5.71	5.86	Si XII 3p satellites
5.92	6.00	Continuum

Flare SOL2002-12-26T08:30 $_{GOES}$C1.9

http://www.cbk.pan.wroc.pl/resik_catalogue.htm



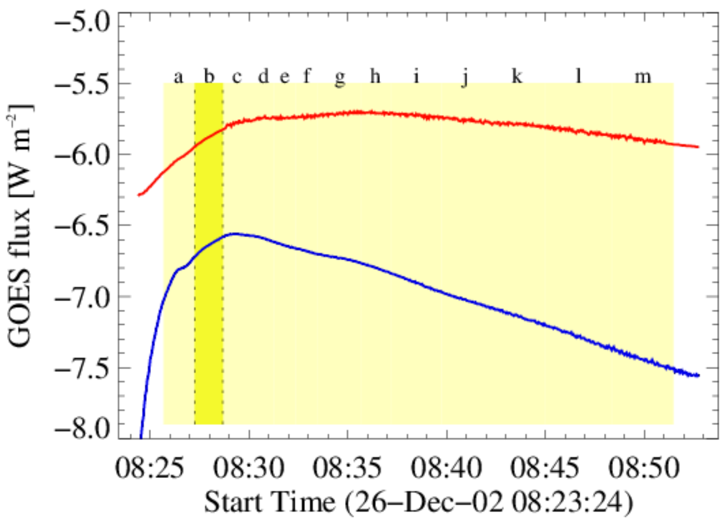
Spectral nights as seen by optical satellite sensor.

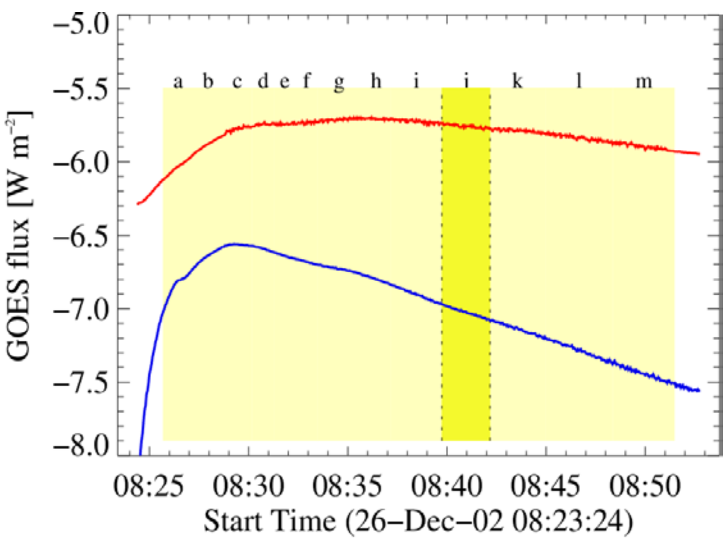
Dark grey areas denote times of radiation belts passages – High Voltage is turned OFF.

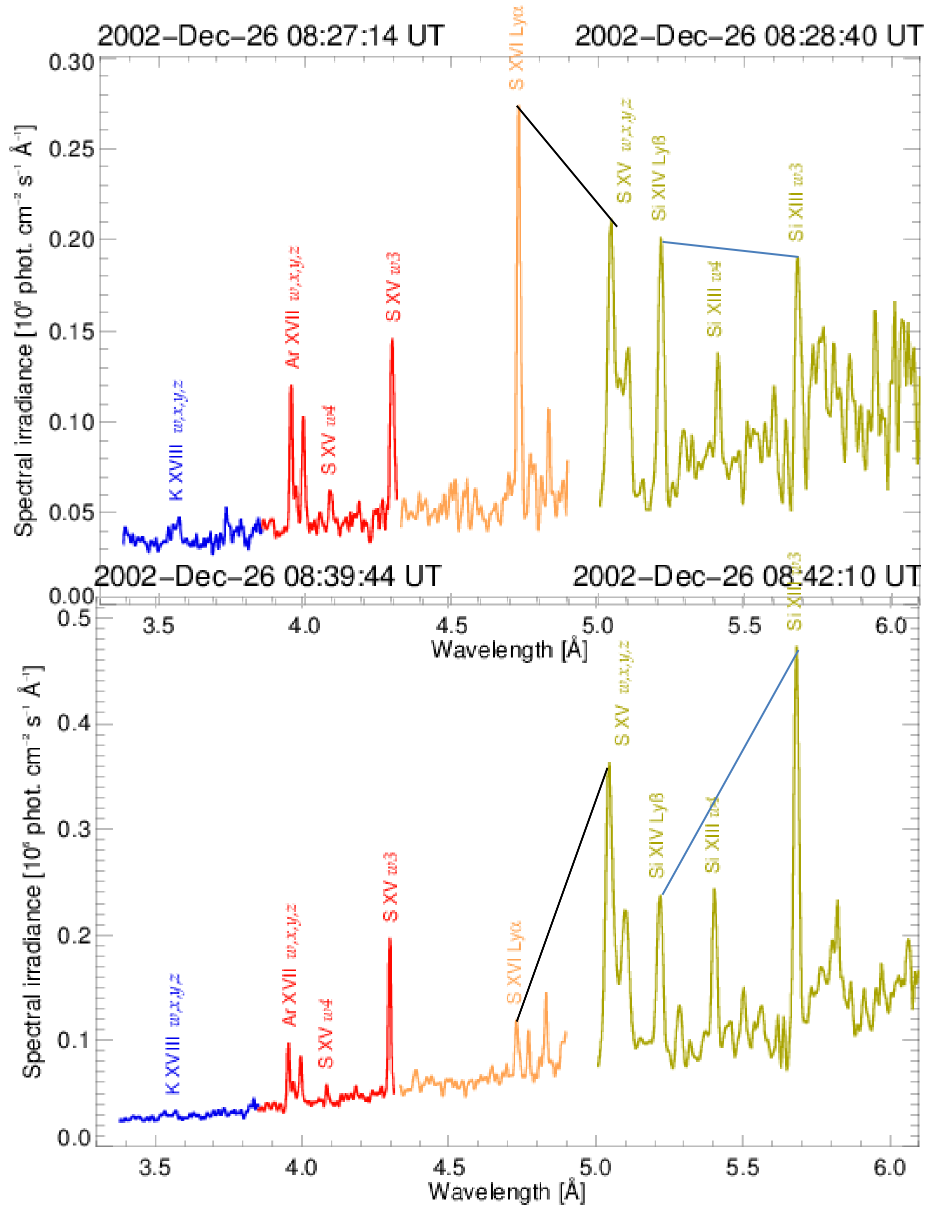
We selected 13 time intervals Δt=75s ÷ 200s duration covering this part of evolution of the event

08:23:00 08:51:00 08:35:00 C1.9 S00E43

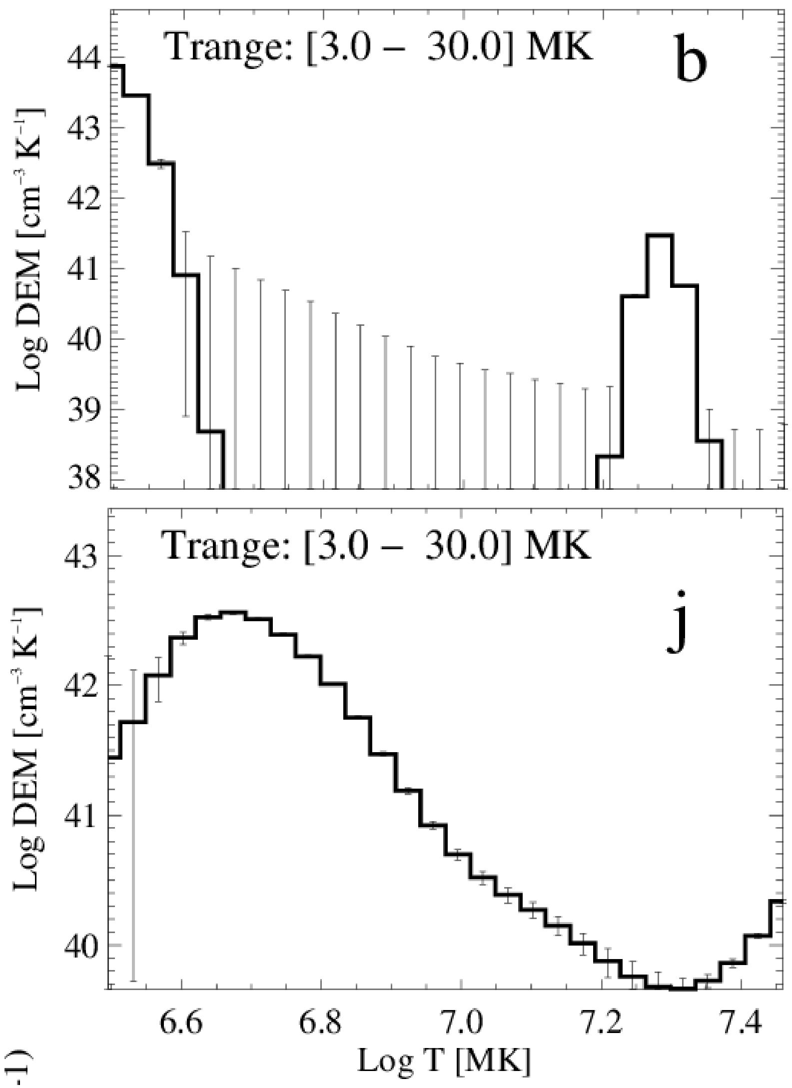
Spectral variability for SOL2002-12-26T08:30

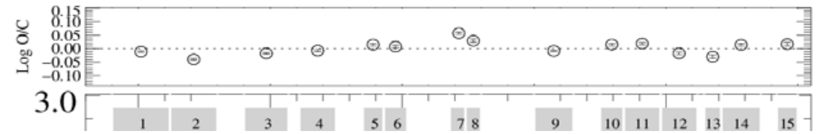




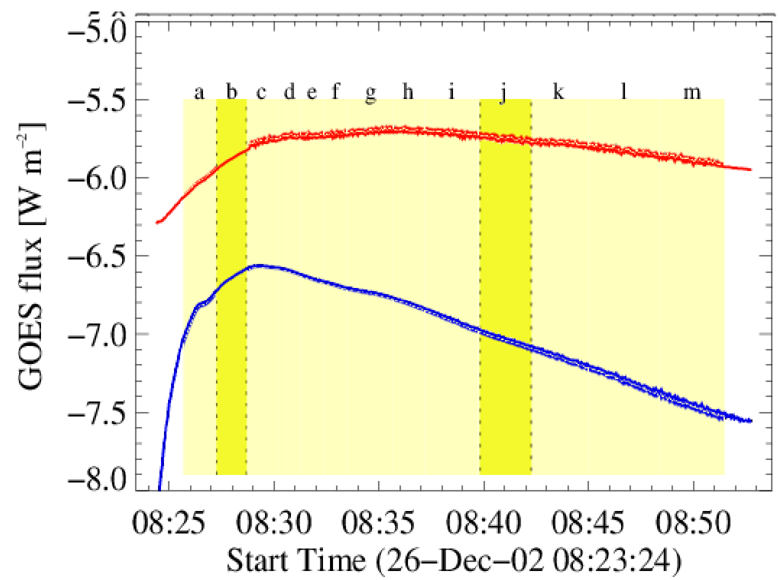


DEM examples: SOL2002-12-26T08:30



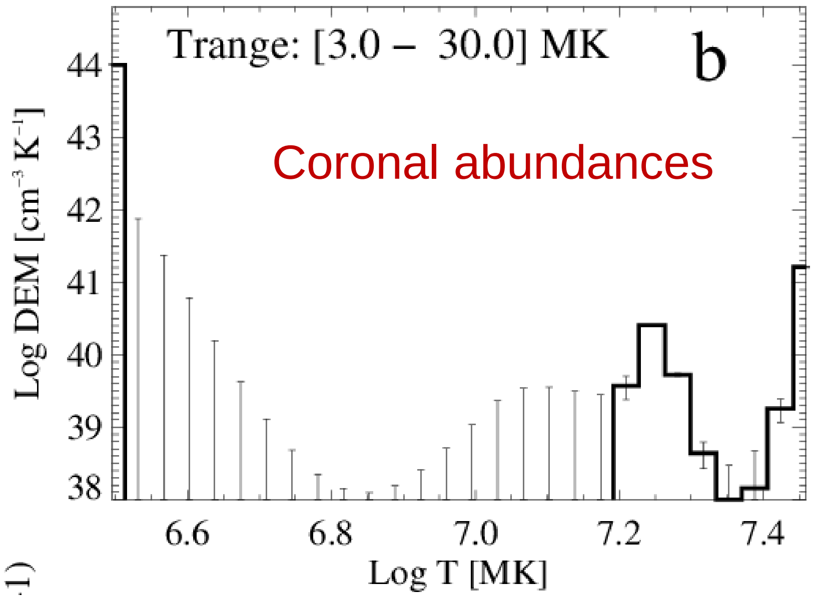


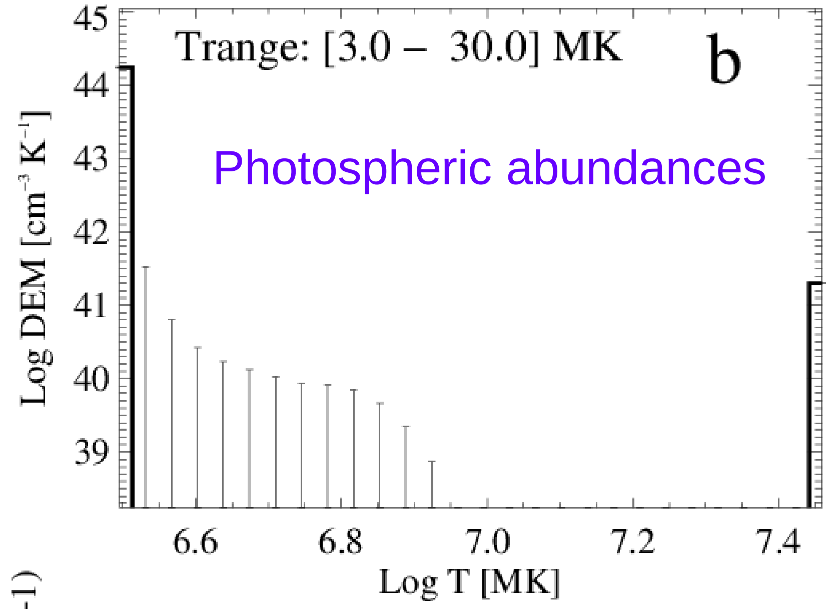
For each selected time interval 10 000 iterations for DEM inversion have been performed. Typically, better than 5 % agreement between observed and DEM predicted fluxes in every spectral band is reached.



Results of DEM inversion are very sensitive to the assumed plasma composition!!!

With identical set of input fluxes, the inversion outcomes are quite different for particular patterns of plasma composition

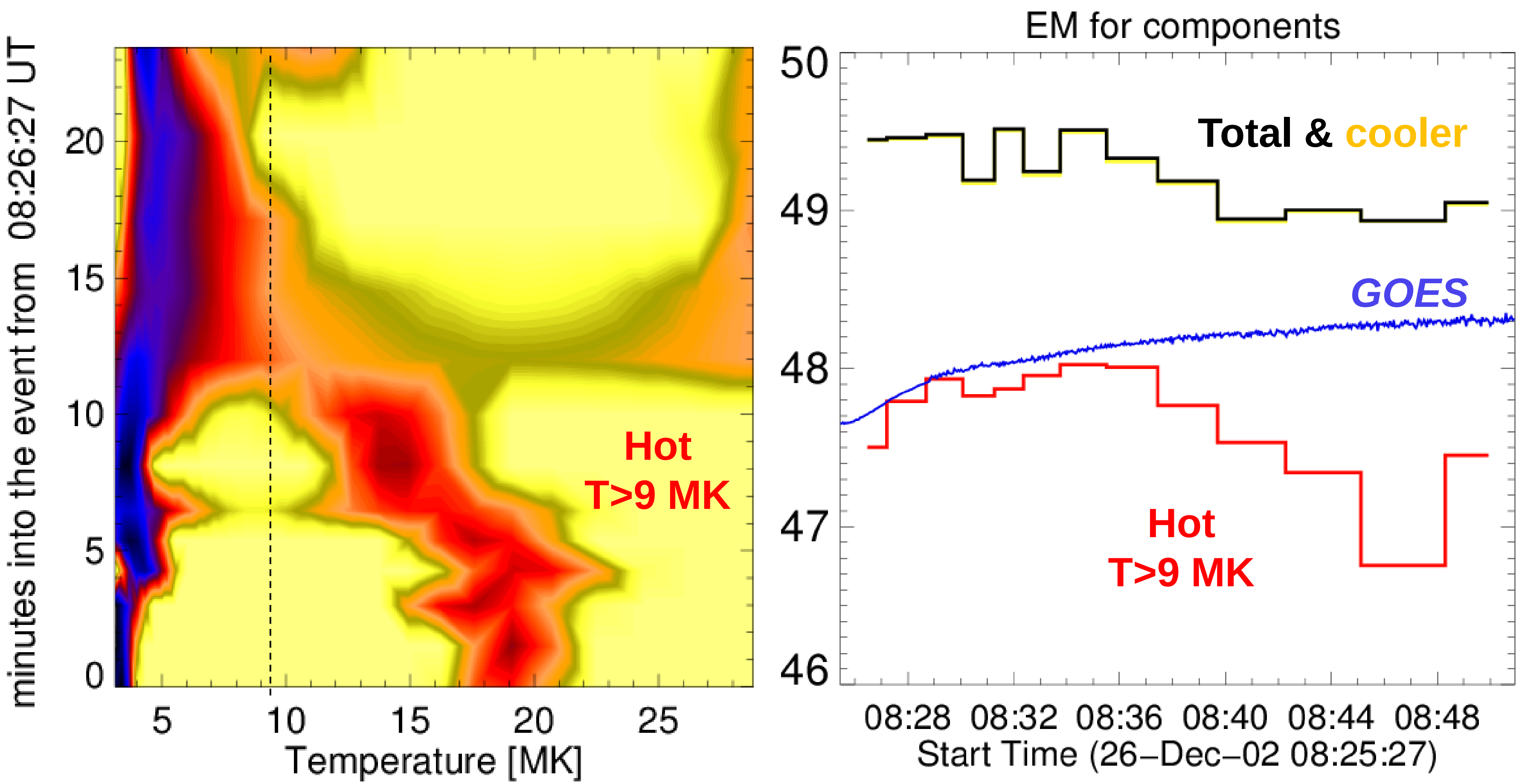




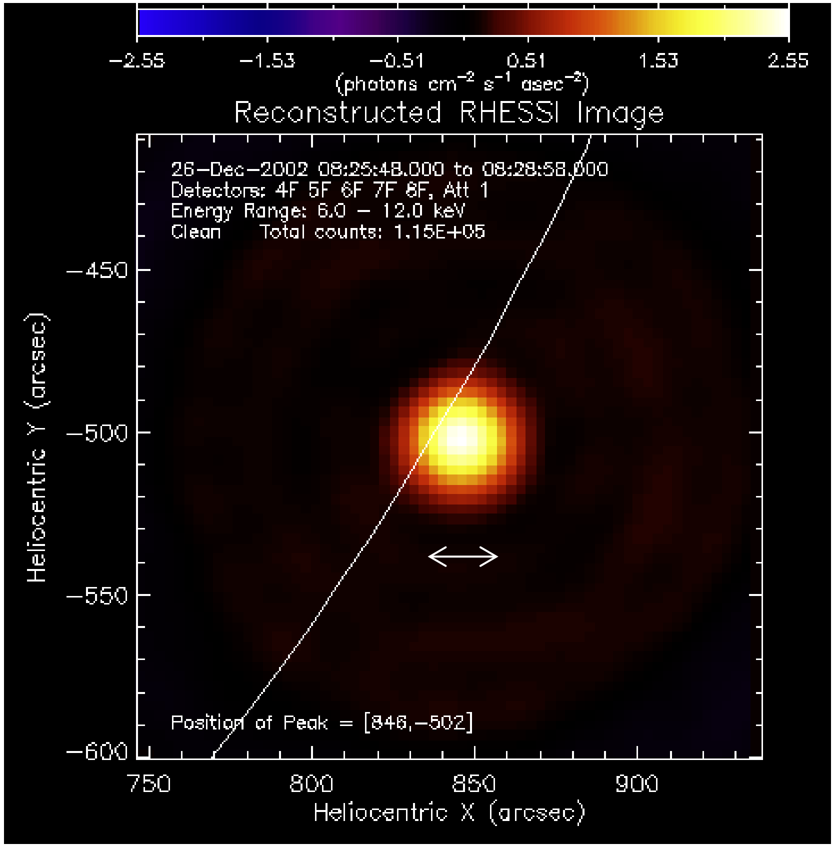
For the set of coronal and photospheric composition patterns the ratios of observed and DEM-predicted fluxes in individual spectral bands exceed 15% and 20% respectively. Overall inversion convergence is worse, if at all observed.

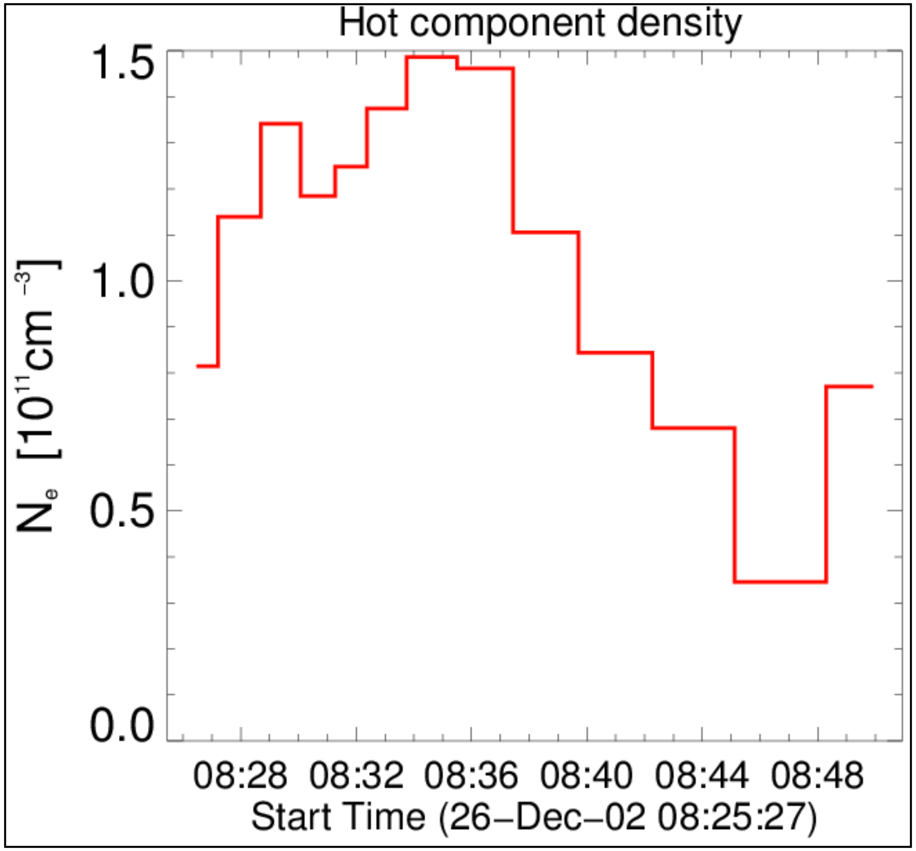
This is in contrary to the situation when the event-optimised pattern of abundances is used as is the case for the present study.

DEM evolution for SOL2002-12-26T08:30



RHESSI for SOL2002-12-26T08:30



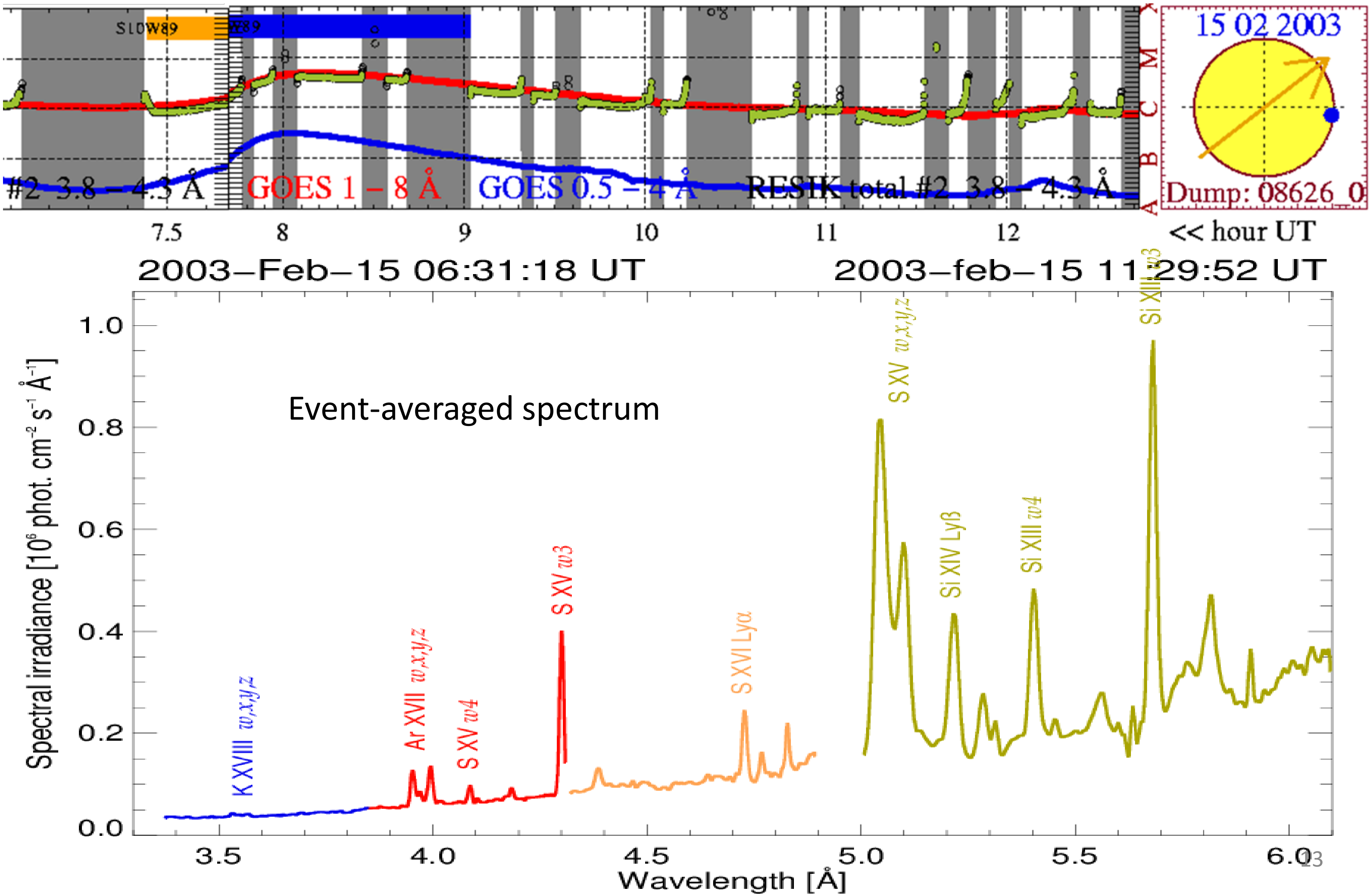


D=4.5 x 10^8 cm

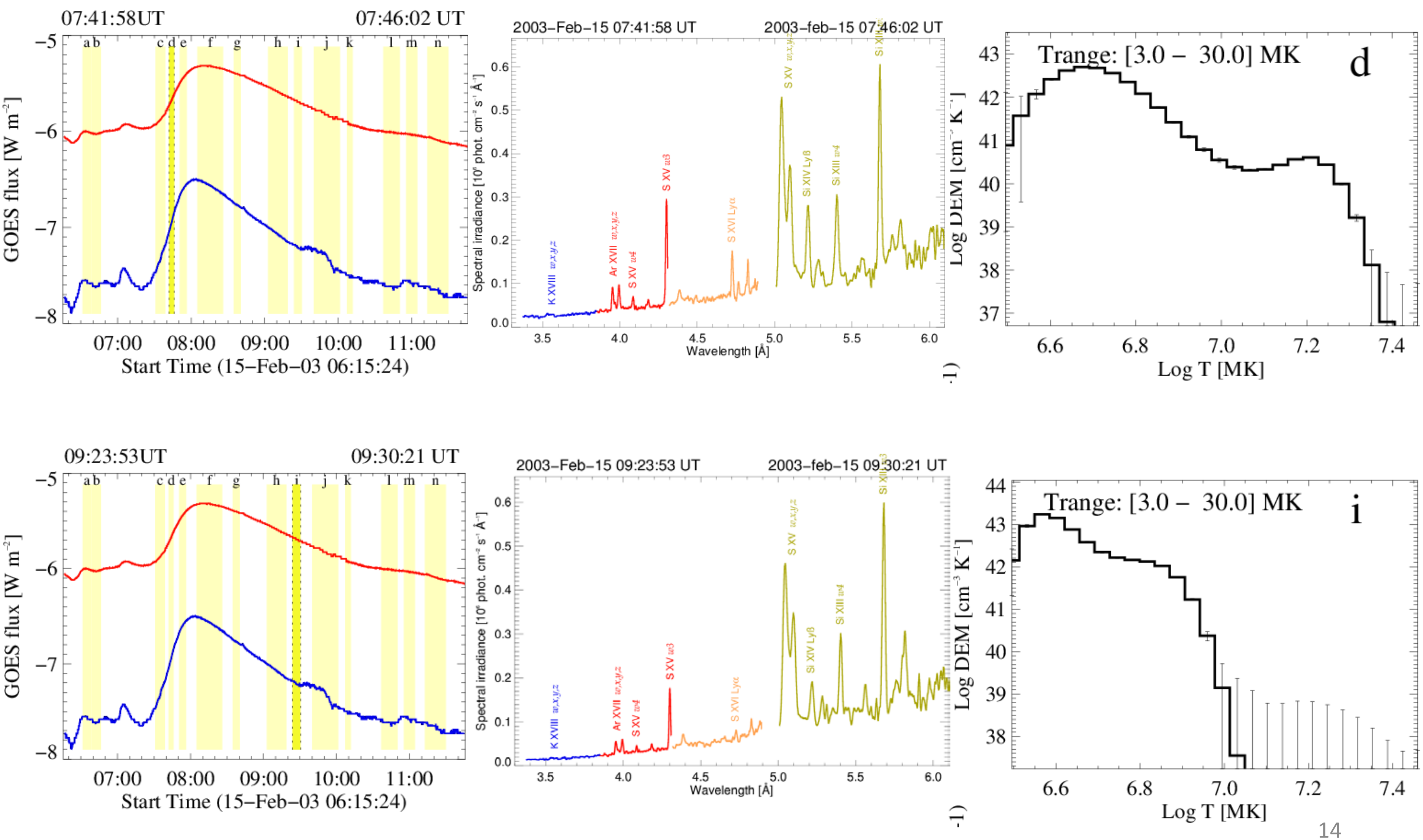
If we consider the total EM of the hot component to be contained in the RHESSI bright kernel, this allows for the estimation of the **density** of hot plasma.

We selected
14 time intervals
Δt= 6.5 min.÷ 21 min.

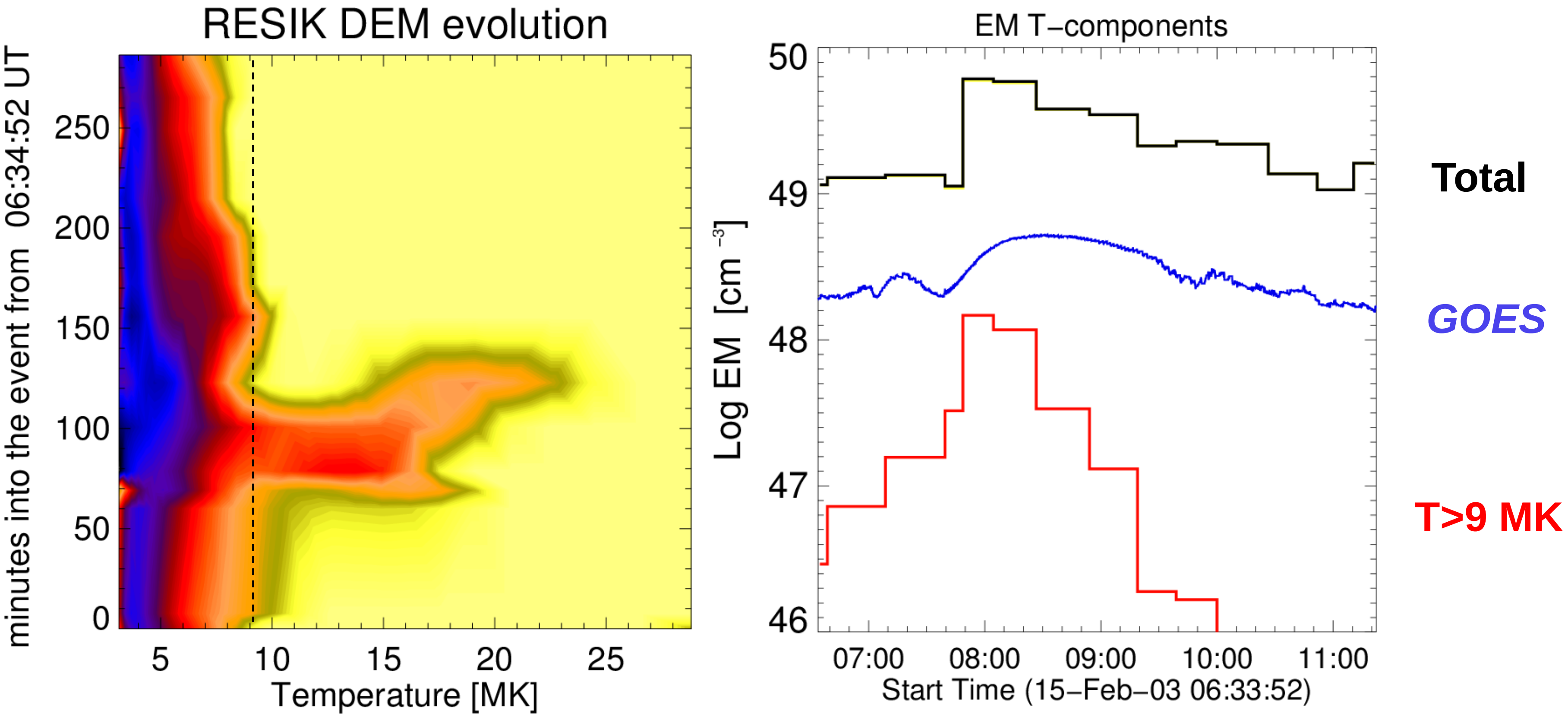
SOL2003-02-15T08:10 C4.5



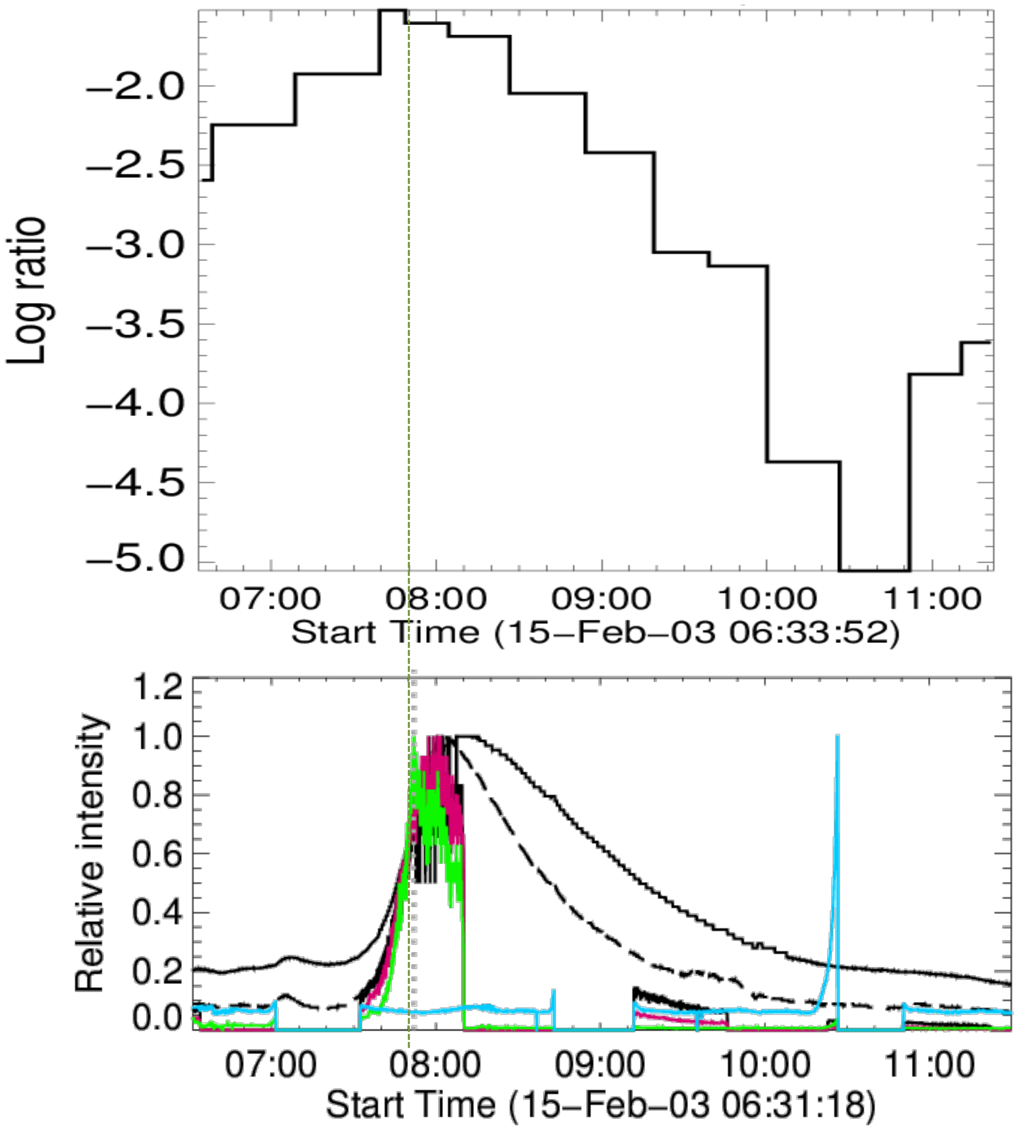
Inverted DEM shapes



DEM evolution for SOL2003-02-15T08:10

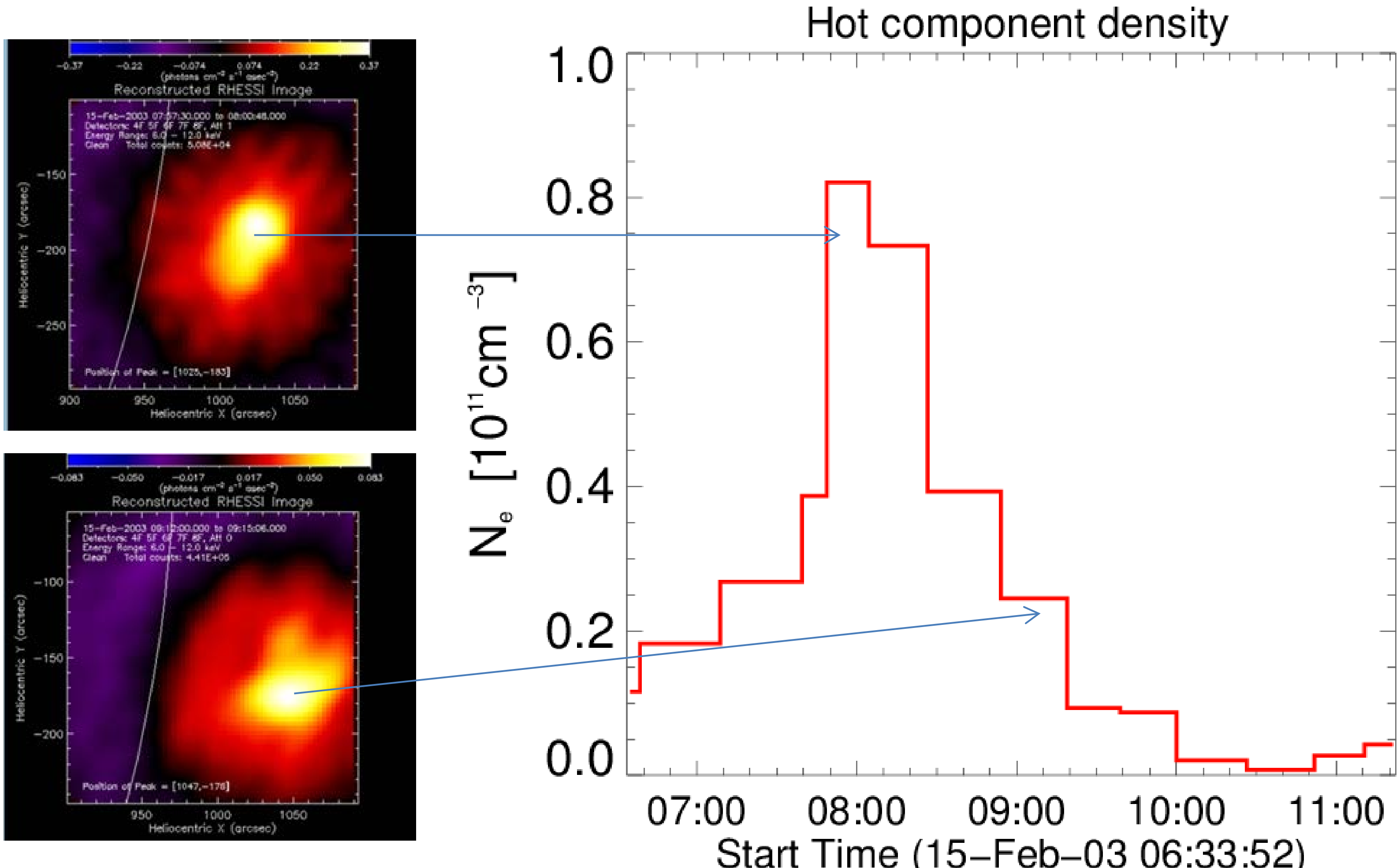


Relative proportion of hot and cold plasma



The highest proportion of hot plasma is at the time of RHESSI 12-25 keV maximum.

RHESSI for SOL2003-02-15T08:10



Changing morphology
of hot component

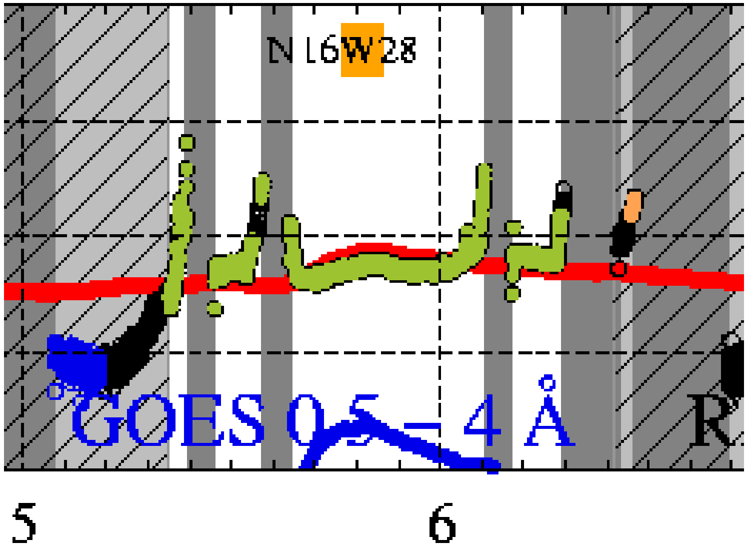
D=7.5x10^8cm

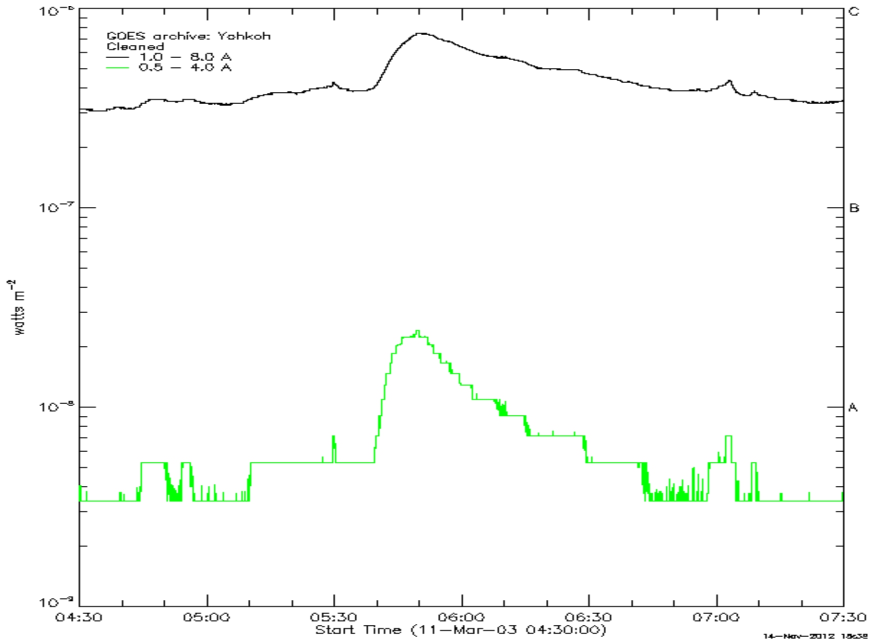
Plasma density is lower in this event

Concluding remarks

- DEM distributions have been calculated using absolutely calibrated RESIK spectra. 15 spectral bands are identified in the range 3.3 Å -- 6.1 Å for the DEM inversion.
- Adjusting the plasma composition is apparently necessary before the DEM inversion (otherwise, the outcome results in biased solutions).
- For two flares, the DEM distributions have two components – a cooler component T < 9 MK (probably related to the non-flaring active region) and a hotter one T > 9 MK (flare proper).
- The total EM of the hotter component is orders of magnitude less than that of the cooler component and declines rapidly in the flare later stages.
- The presence of this tiny amount of hot plasma is nevertheless necessary in the data analysis for the observed fluxes in several spectral bands to be reproduced.
- With the emitting region size from imaging instruments like RHESSI, a lower limit for the density of plasma can be estimated: typically this is near 10^{11} cm^{-3} near the flare peak.

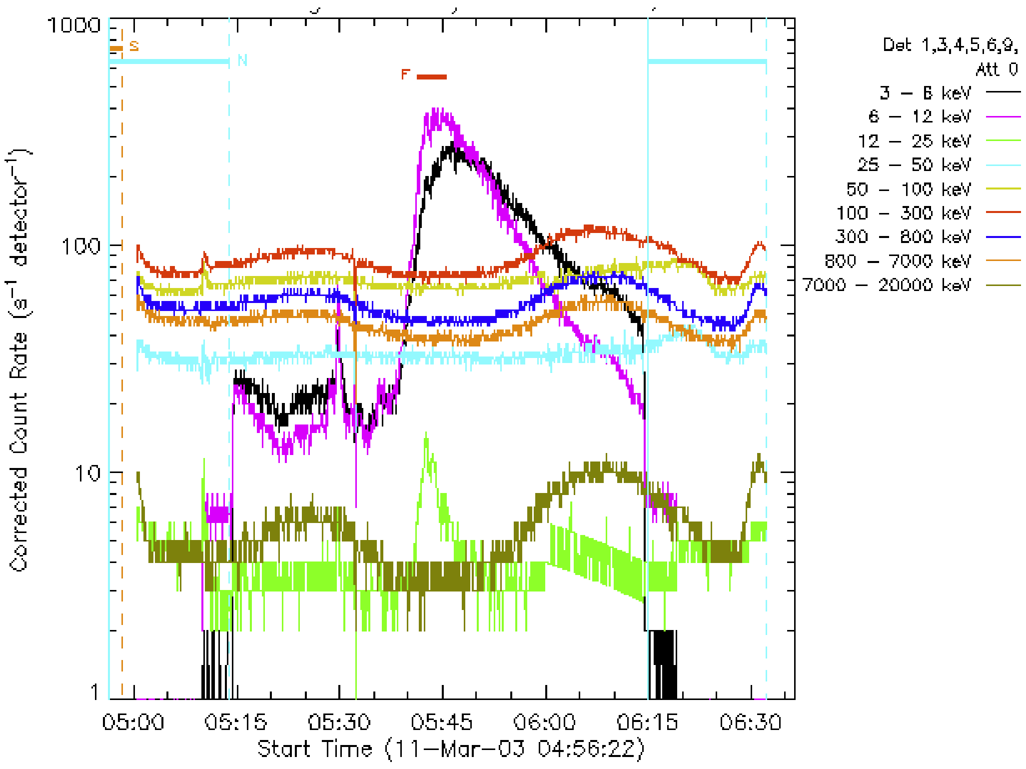
SOL2003-03-11T05:50 B7.3



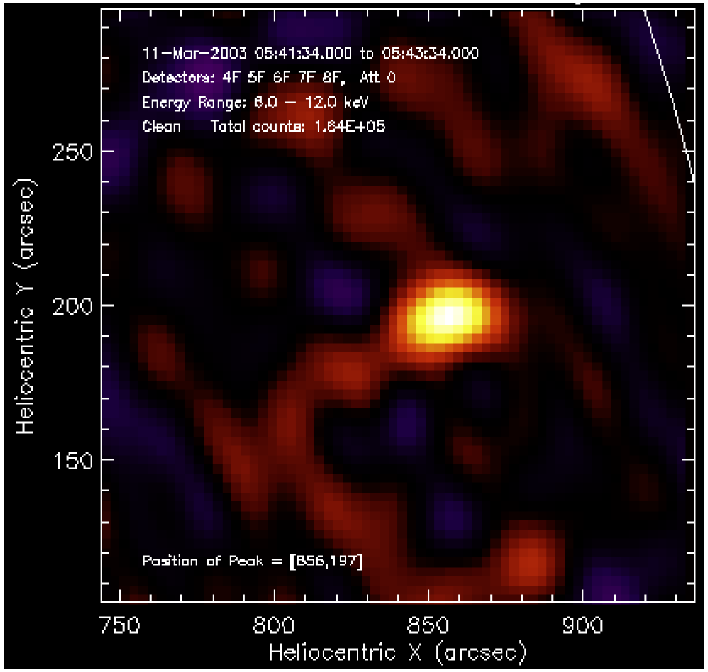


2003/03/11 05:46:00 05:52:00 05:50:00 B7.3
N16W28

RHESSI



Corrected Count Rate (s^{-1} detector^{-1})
1000
100
10
1
S
N
F
05:00
05:15
05:30
05:45
06:00
06:15
06:30
Start Time (11-Mar-03 04:56:22)
Det 1,3,4,5,6,9,
Att 0
3 – 6 keV
6 – 12 keV
12 – 25 keV
25 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 800 keV
800 – 7000 keV
7000 – 20000 keV



11-Mar-2003 05:41:34.000 to 05:43:34.000
Detectors: 4F 5F 6F 7F 8F, Att 0
Energy Range: 6.0 – 12.0 keV
Clean Total counts: 1.64E+05
Position of Peak = [856,197]
Heliocentric Y (arcsec)
250
200
150
750
800
850
900
Heliocentric X (arcsec)

THANK YOU