



eHeroes activity



# Multitemperature solar plasma diagnostics from RESIK spectra

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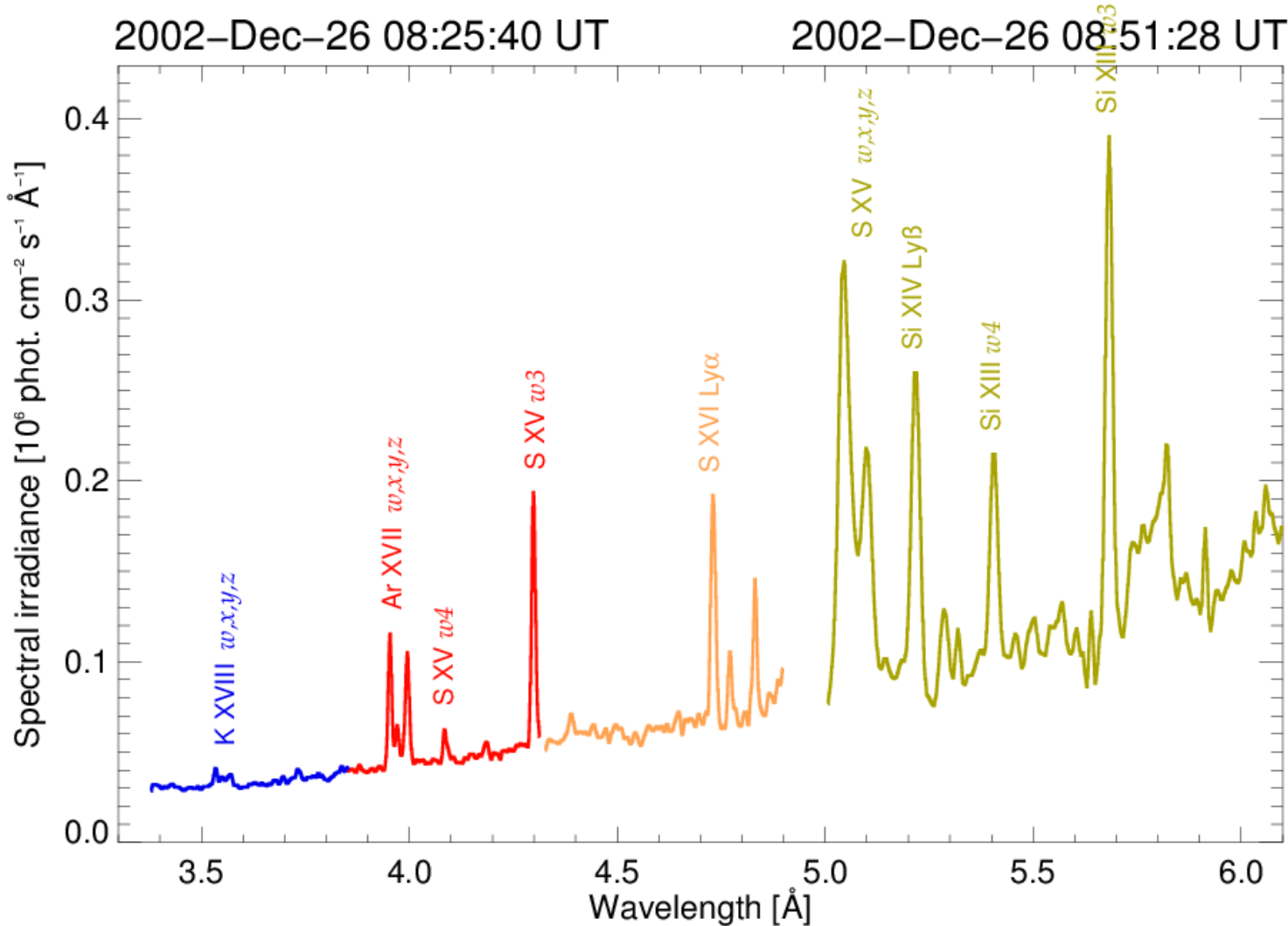
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# RESIK

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, multithermal plasma:

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

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

$$\text{DEM} \equiv \Phi(T) \equiv Ne^2 dV/dT \quad \text{is non-negative}$$

$F_i$  → 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

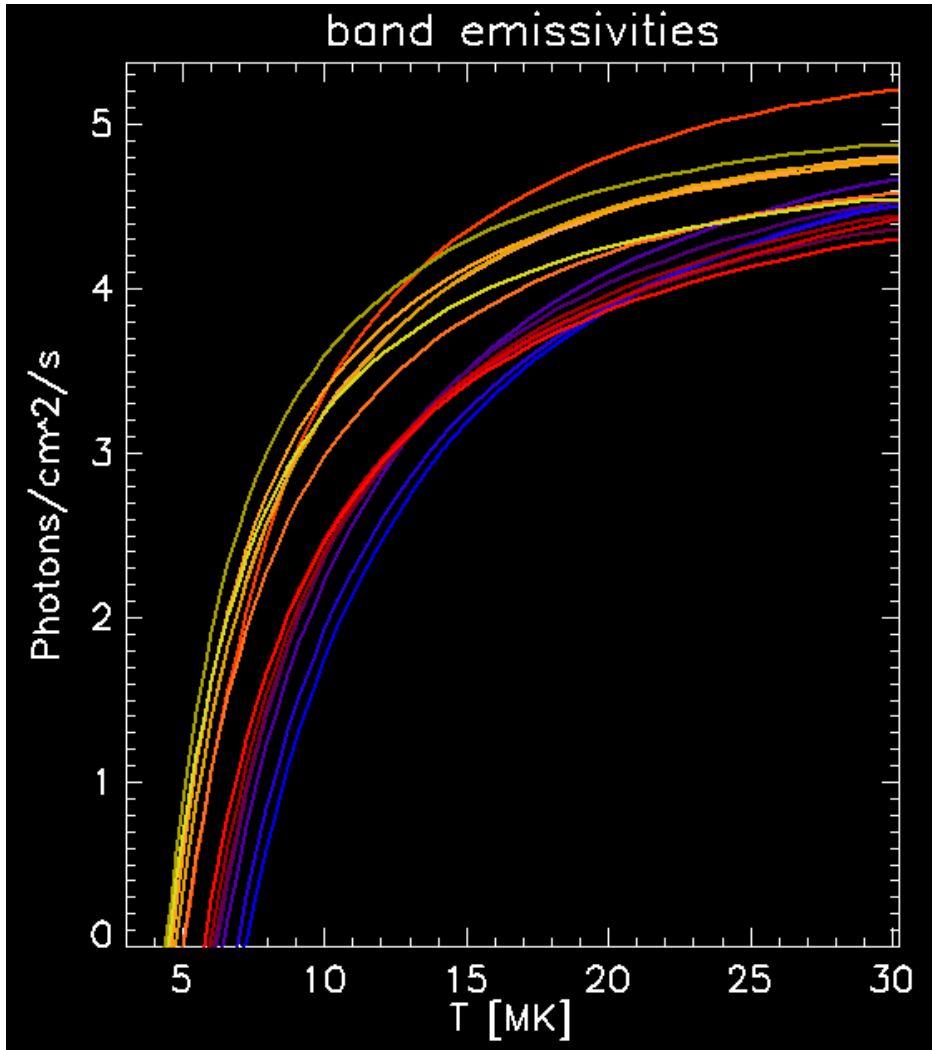
From reduced absolute RESIK spectra we have selected 15 narrow spectral bands embracing the most intense lines and the continuum below. We determined the time-changing fluxes in these bands for flares selected in this research. These fluxes constitute the input set for the differential emission measure (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 (ApJ papers). 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. 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



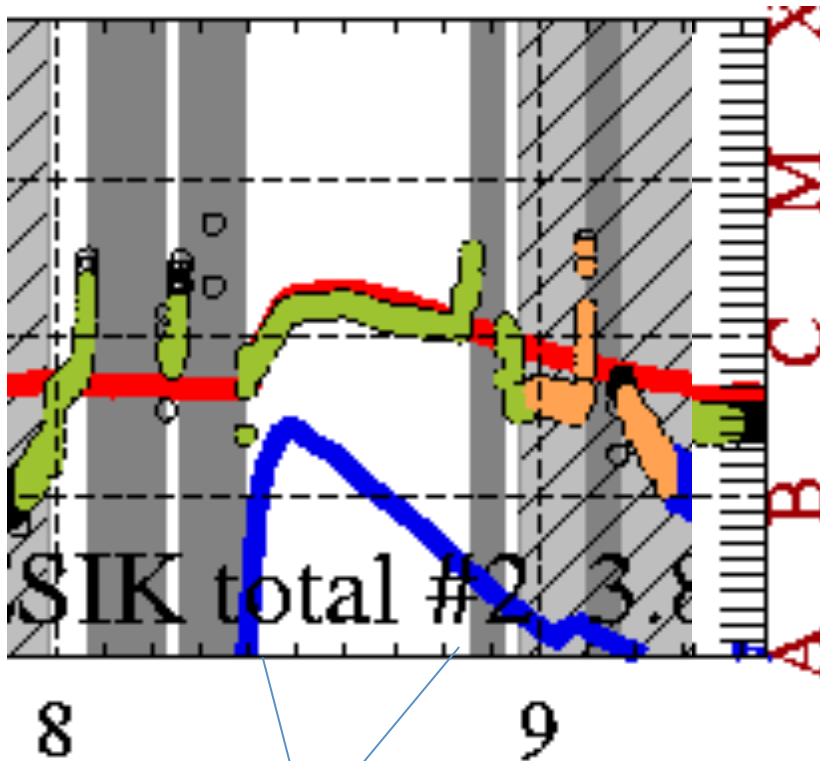
$\Delta\lambda$  [Å]

3.40	3.62	K XVIII triplet ch #1
3.62	3.80	Ar XIII Ly $\alpha$ 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 $1s$ - $3p$ Ly $\alpha$
4.74	4.80	Si XIV $1s$ - $5p$ Ly $\delta$
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](http://www.cbk.pan.wroc.pl/resik_catalogue.htm)



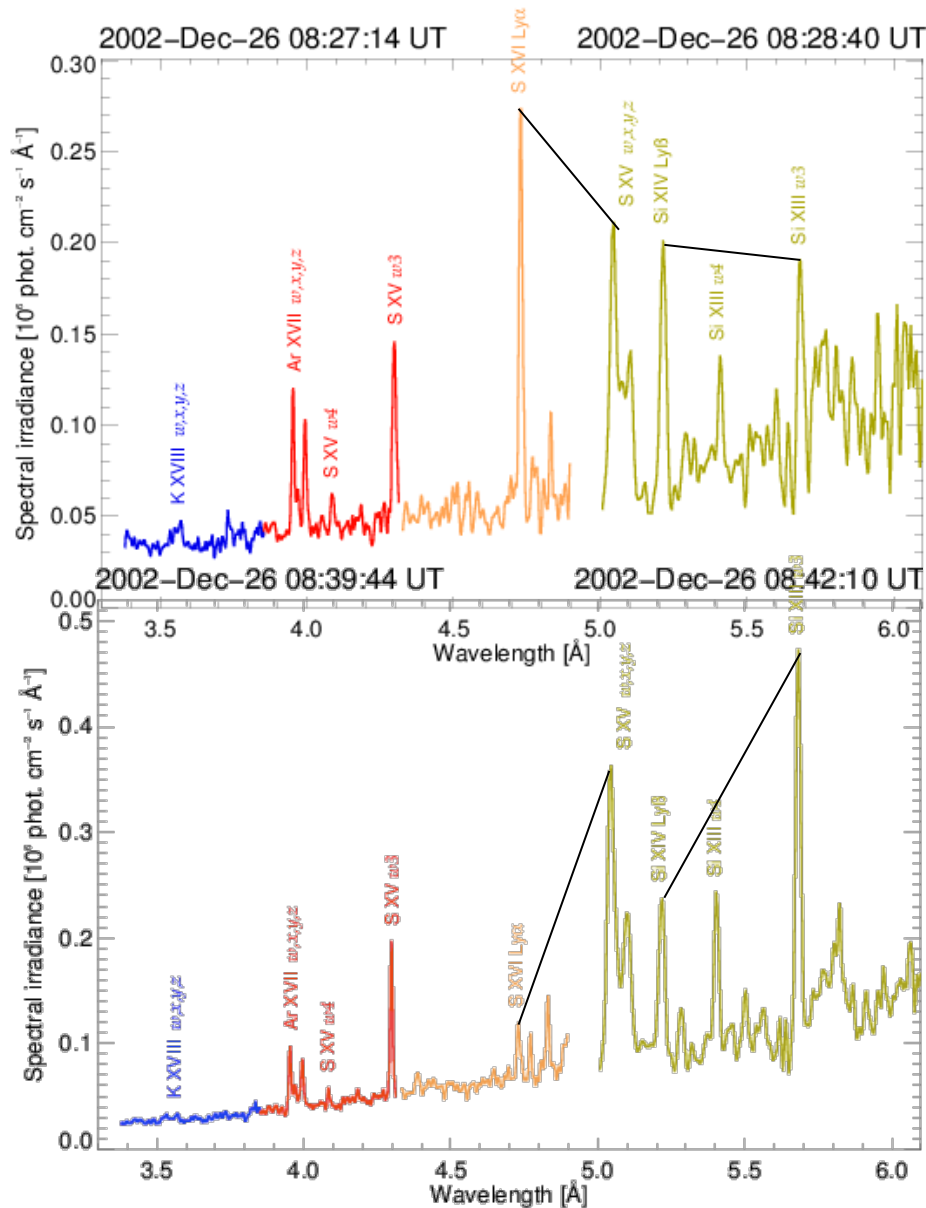
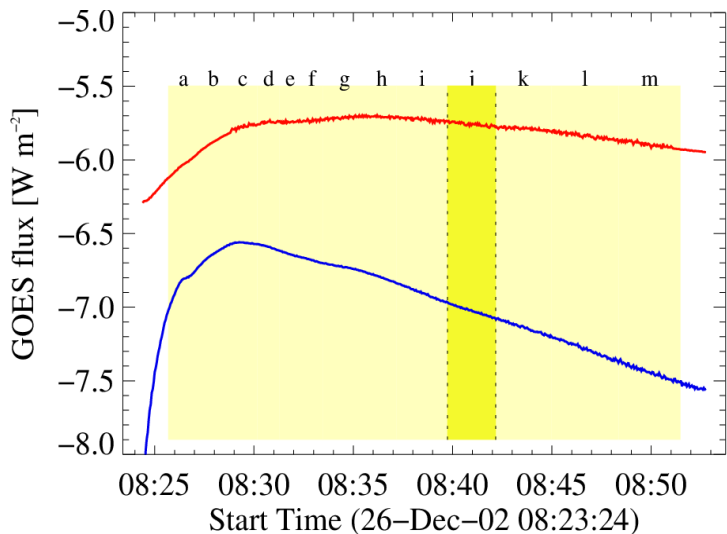
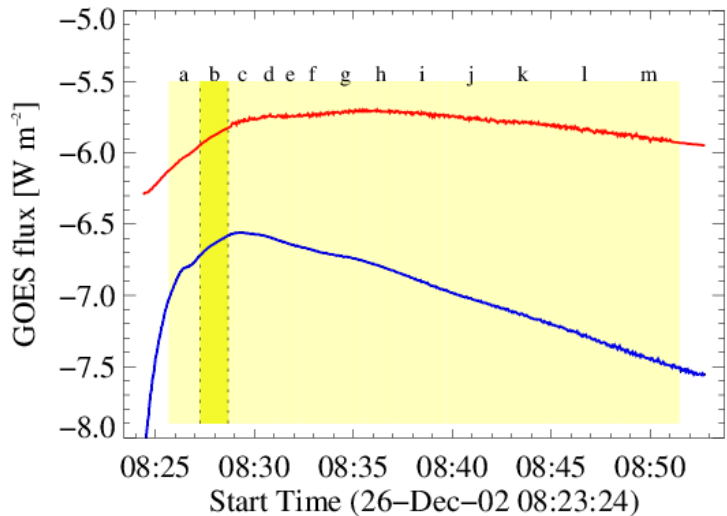
Spectral nights as seen by optical satellite sensor.

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

We selected 13 time intervals  $\Delta t=75s \div 200s$  duration covering this part of evolution of the event

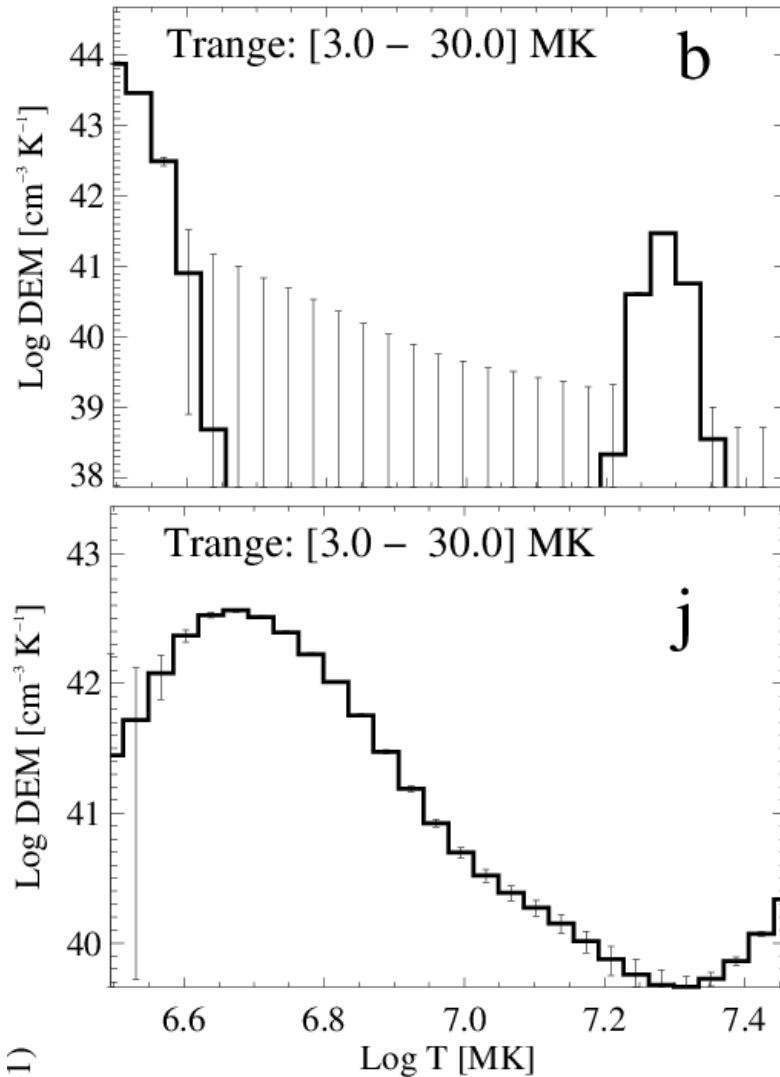
08:23:00 08:51:00 08:35:00 C1.9 S00E43

# Spectral variability for SOL2002-12-26T08:30

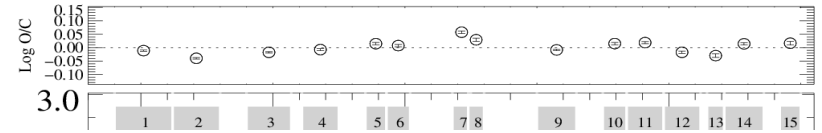




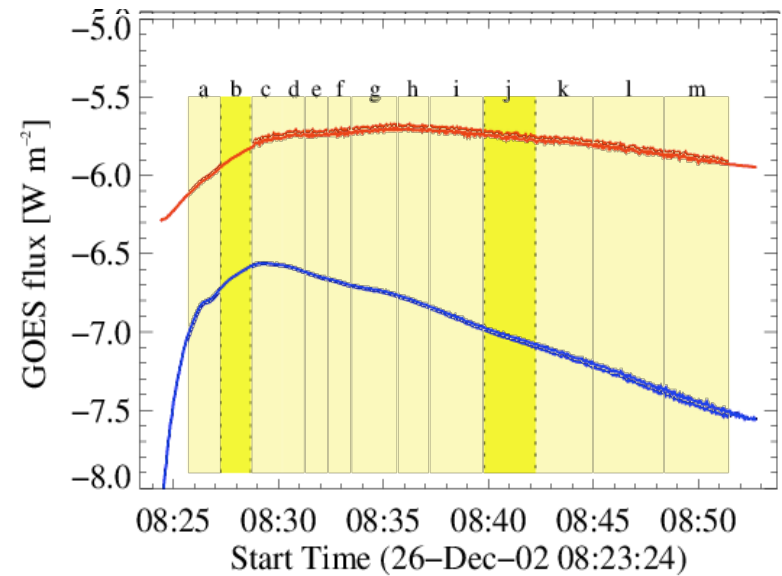
# DEM examples: SOL2002-12-26T08:30



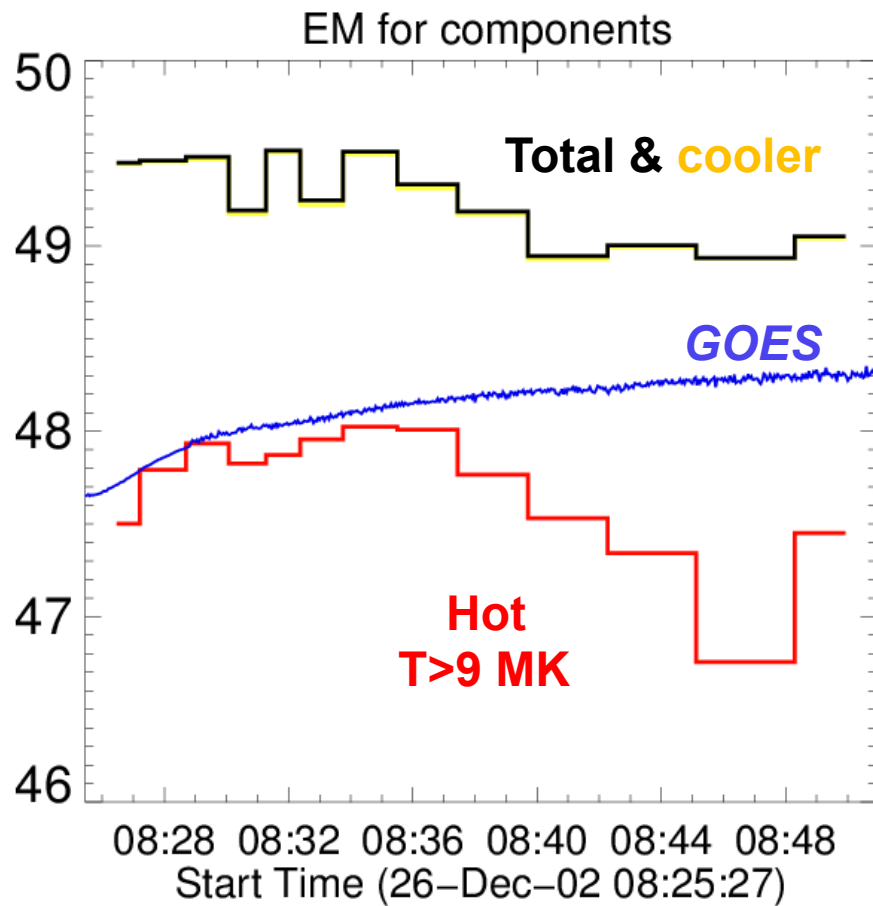
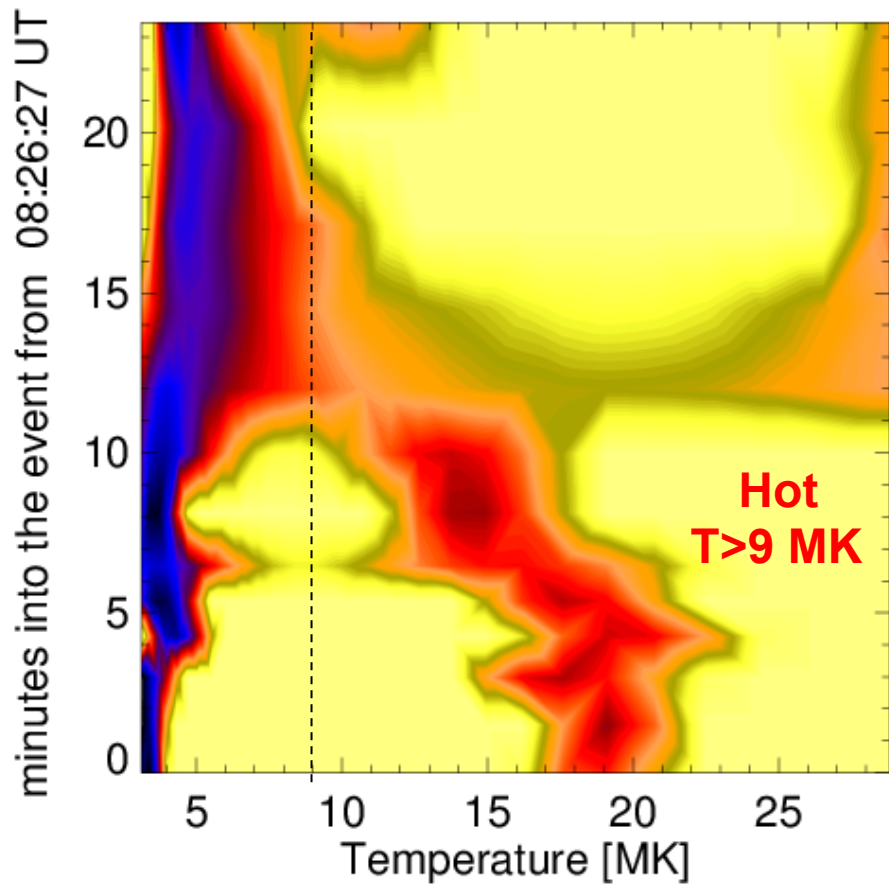
-1)



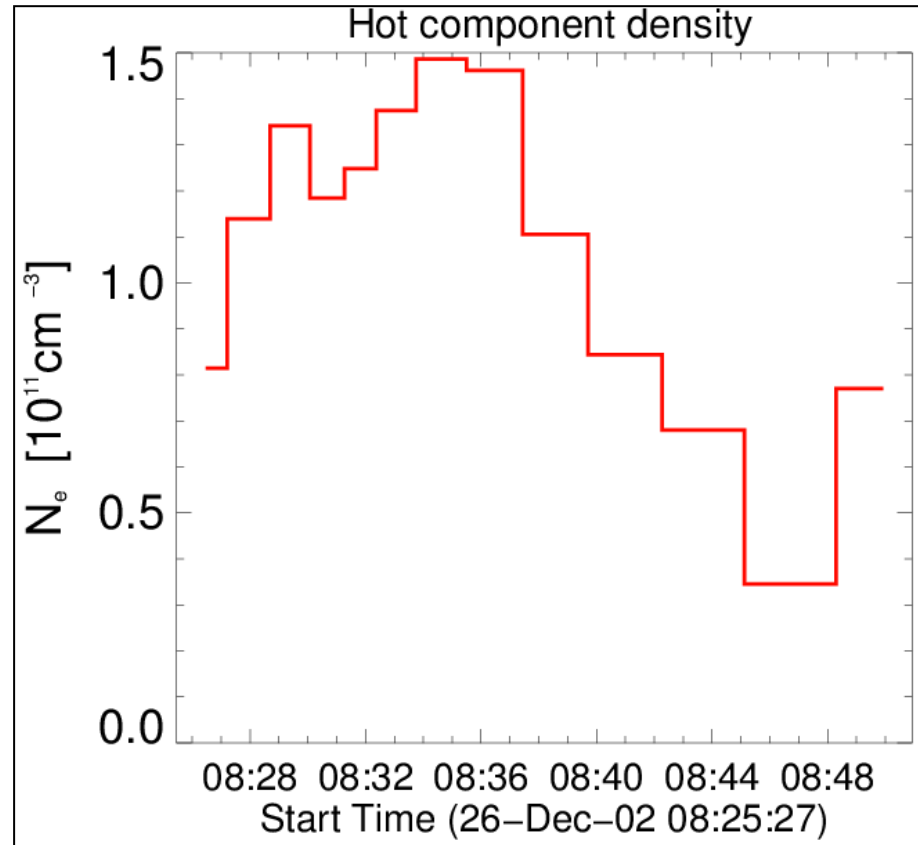
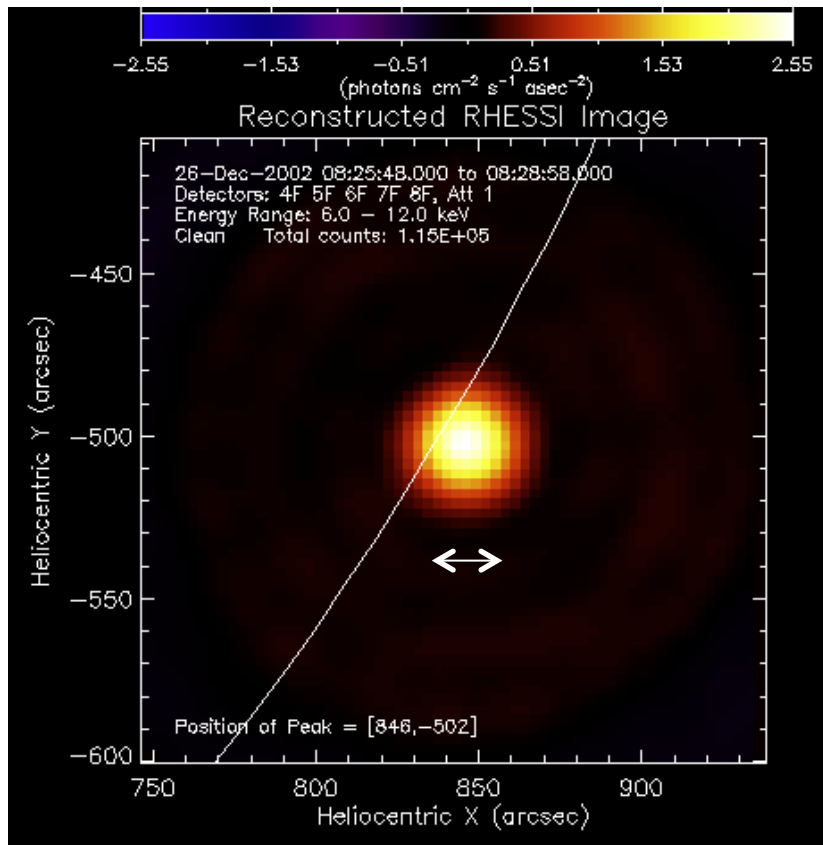
For each selected time interval 10 000 iterations for DEM inversion have been performed. Typically, better than 5 % agreement between observed and DEM predicted fluxes in every spectral band is reached.



# DEM evolution for SOL2002-12-26T08:30



# RHESSI for SOL2002-12-26T08:30

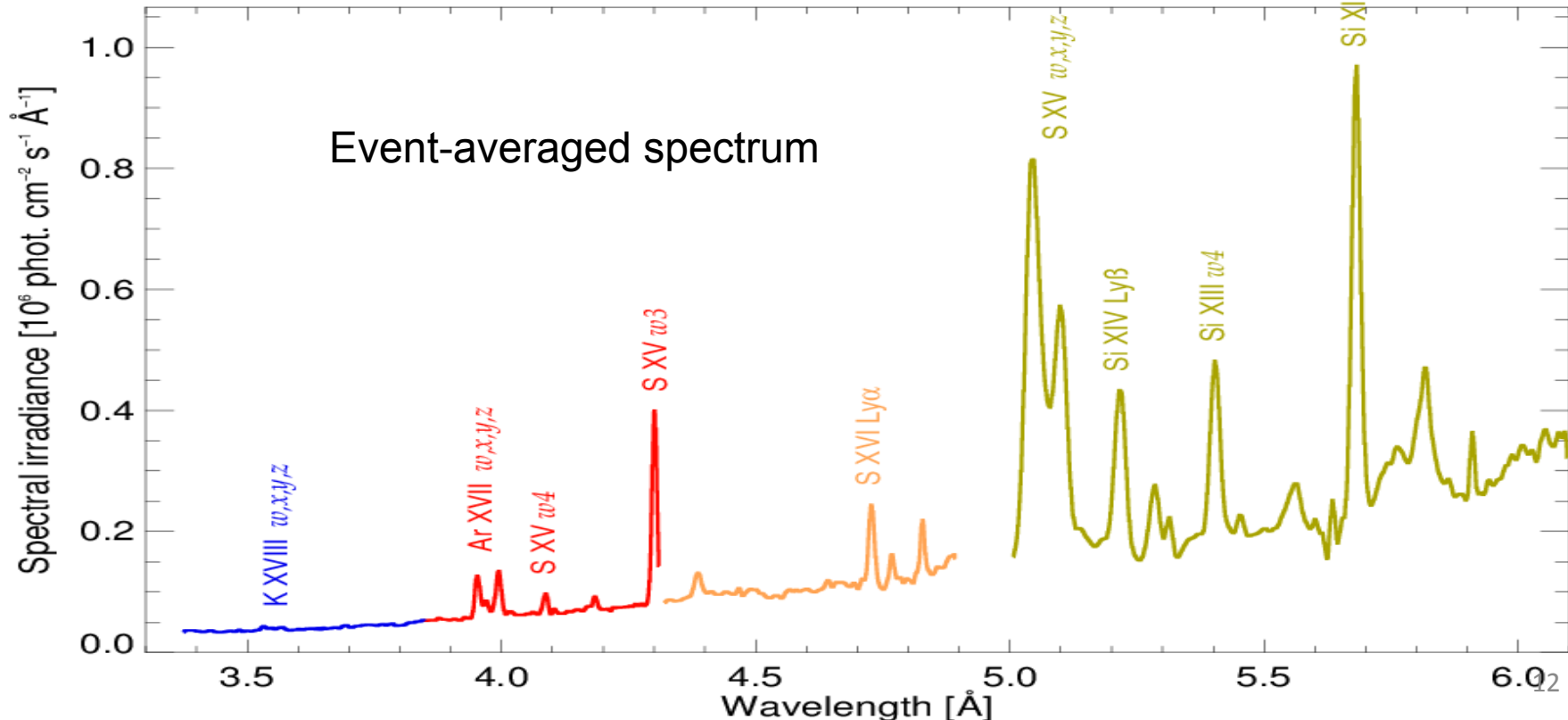
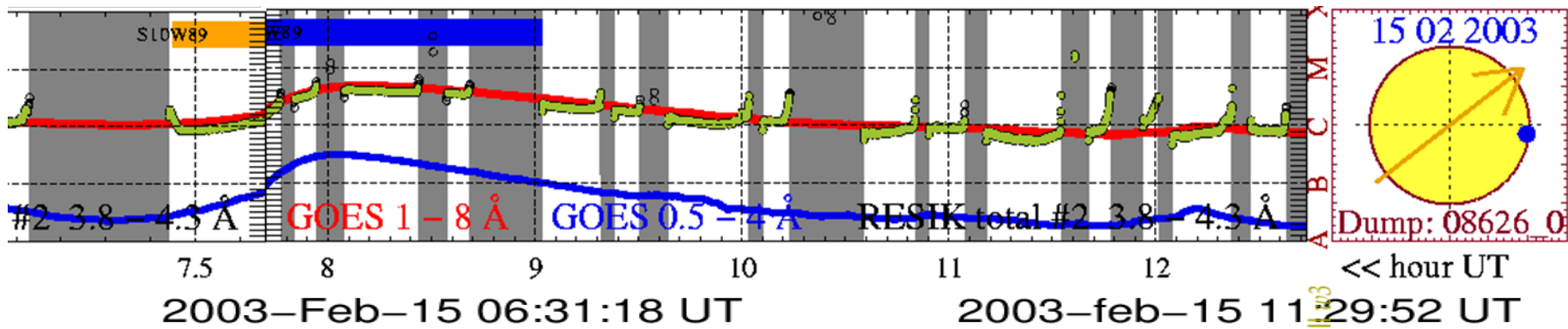


$$D = 4.5 \times 10^8 \text{ cm}$$

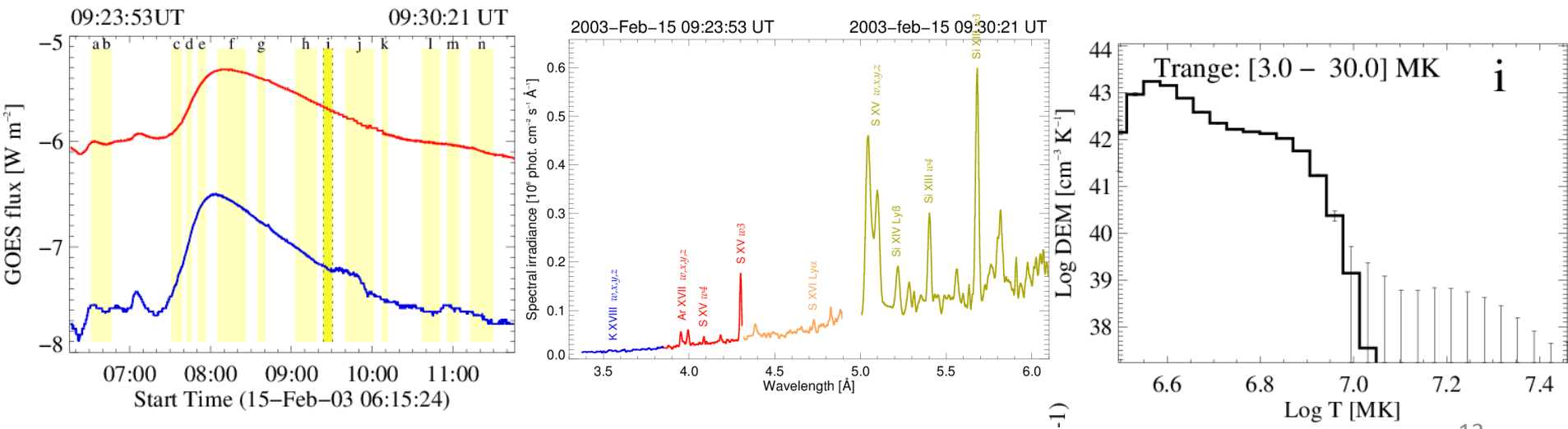
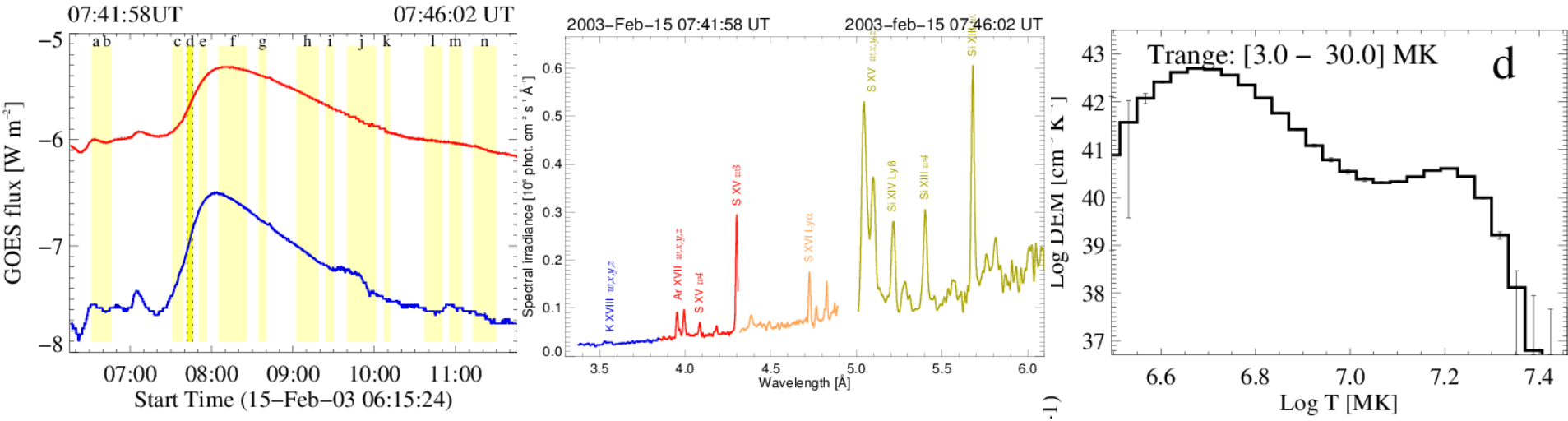
If we consider the total EM of the hot component to be contained in the RHESSI bright kernel, this allows for the estimation of the **density** of hot plasma.

We selected  
 14 time intervals  
 $\Delta t = 6.5 \text{ min.} \div 21 \text{ min.}$

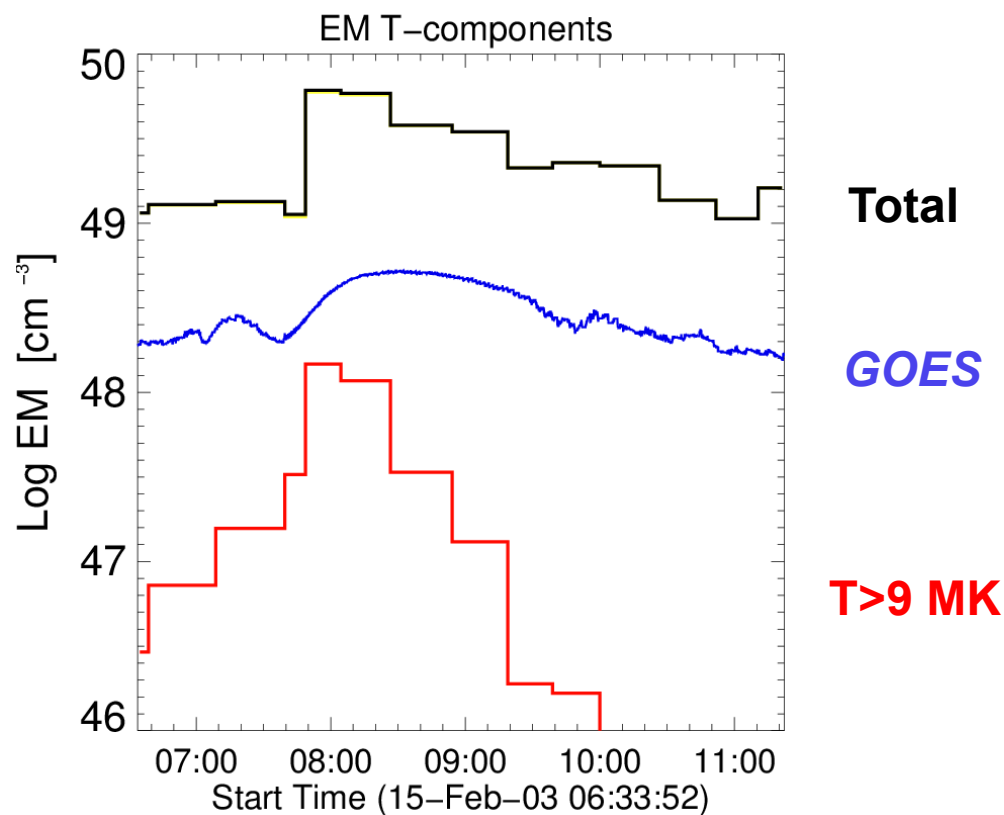
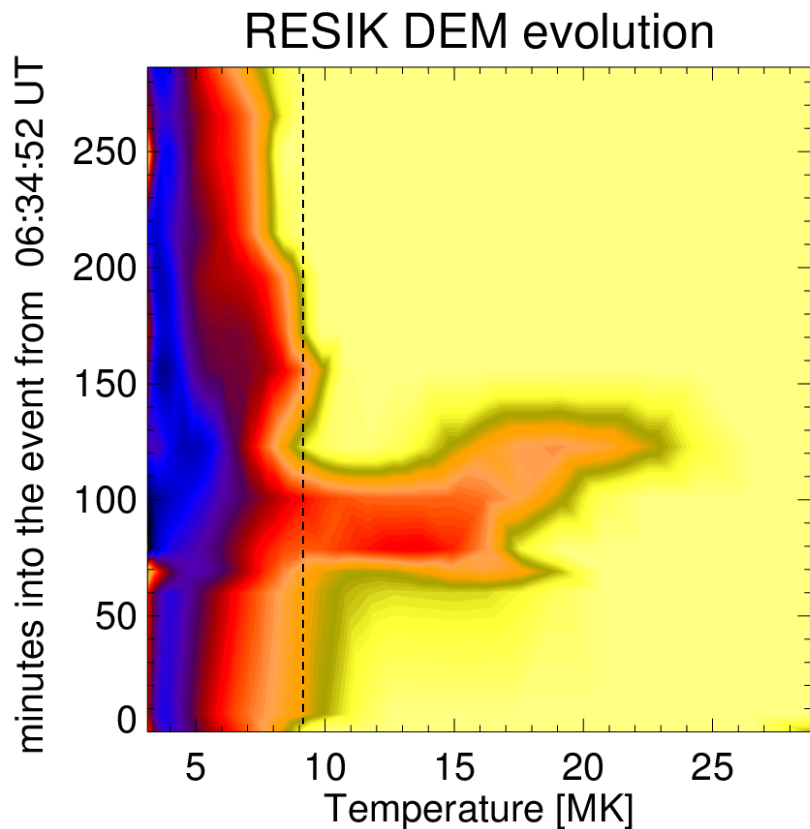
# SOL2003-02-15T08:10 C4.5



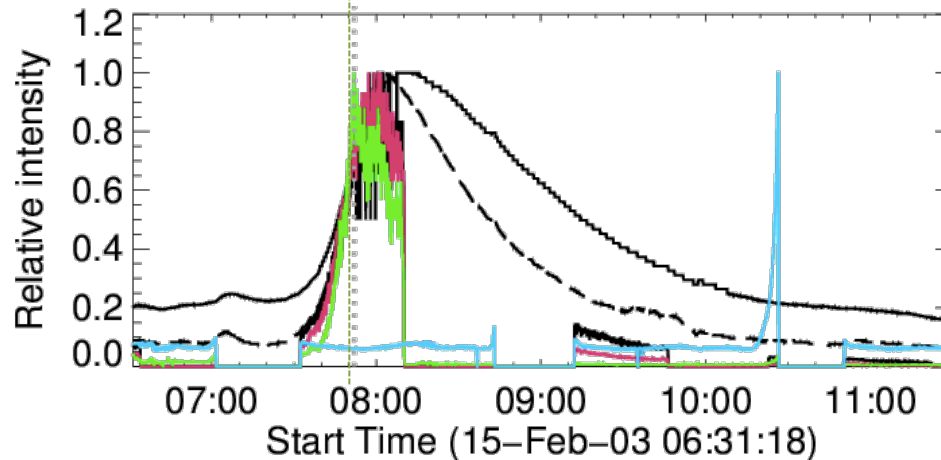
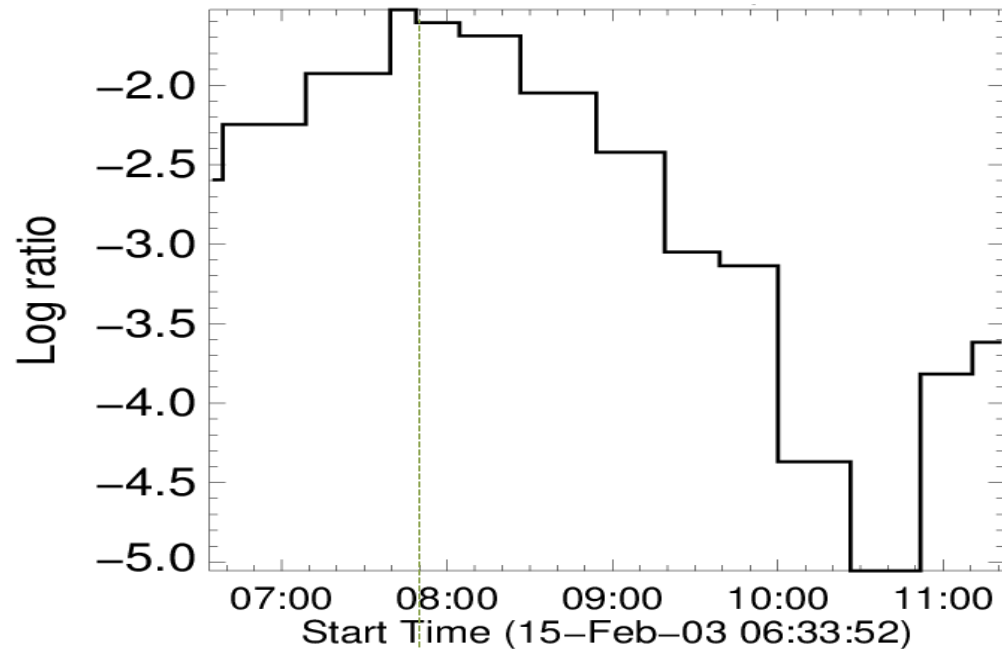
# Inverted DEM shapes



# DEM evolution for SOL2003-02-15T08:10



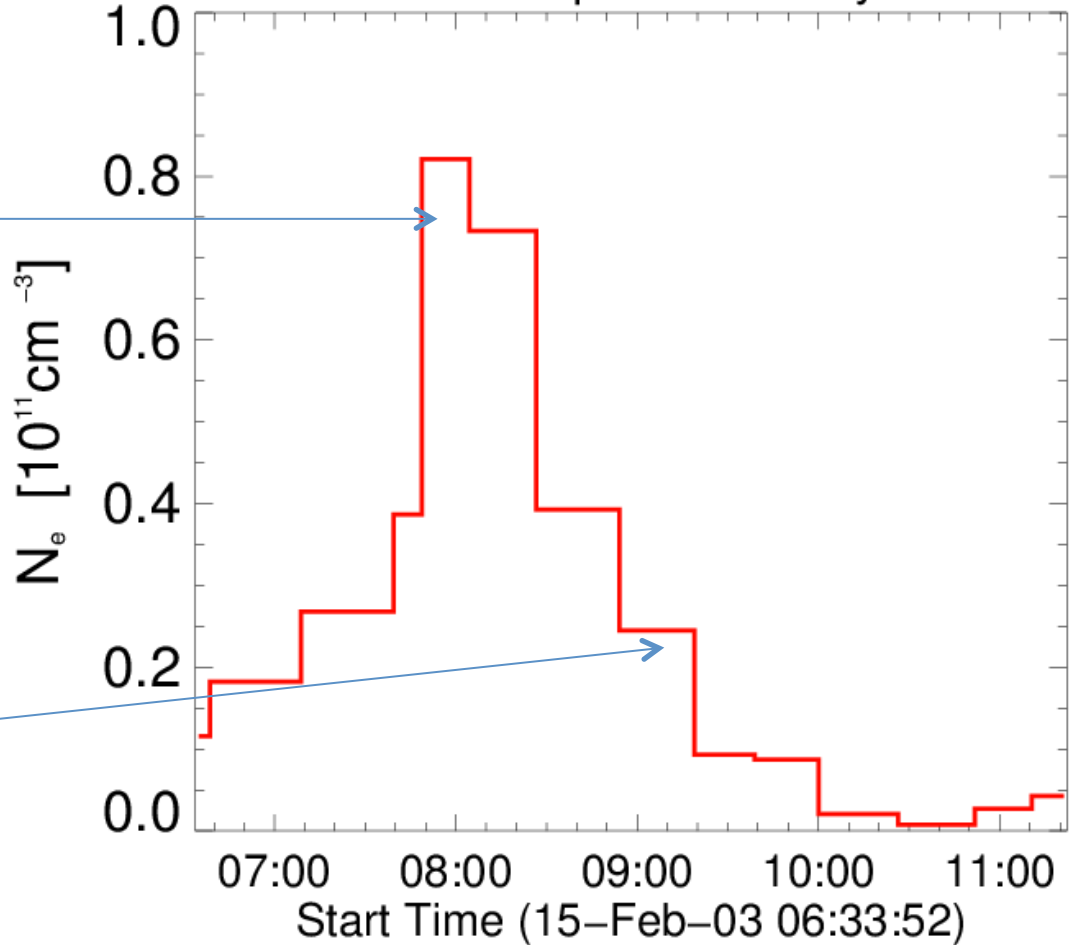
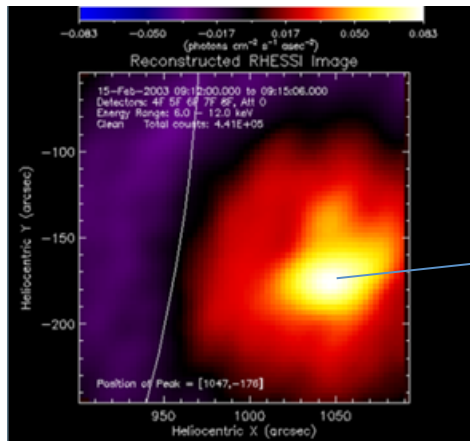
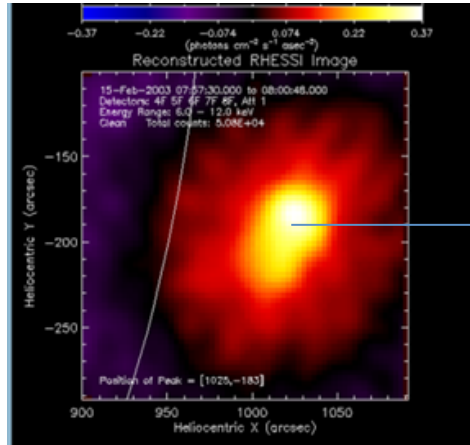
# Relative proportion of hot and cold plasma



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

# RHESSI for SOL2003-02-15T08:10

Hot component density



Changing morphology of hot component

$$D = 7.5 \times 10^8 \text{ cm}$$

Plasma density is lower in this case.



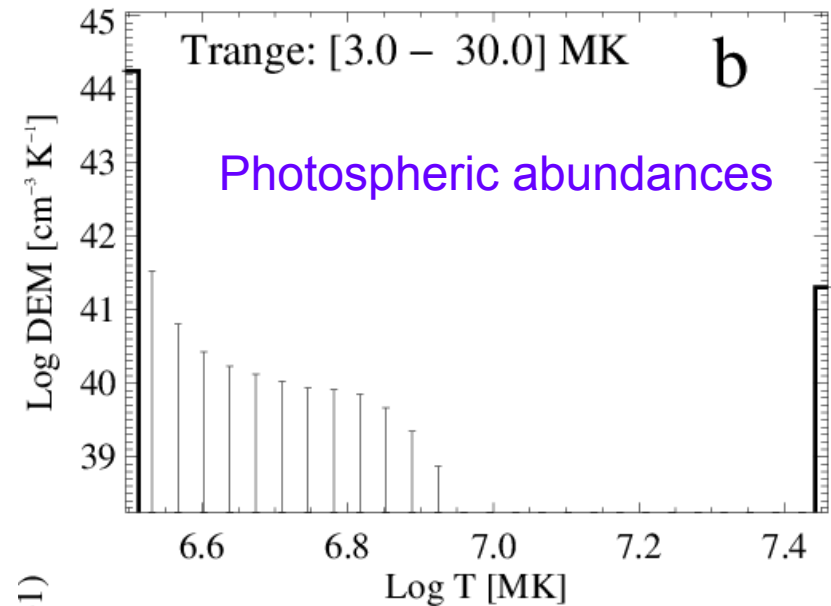
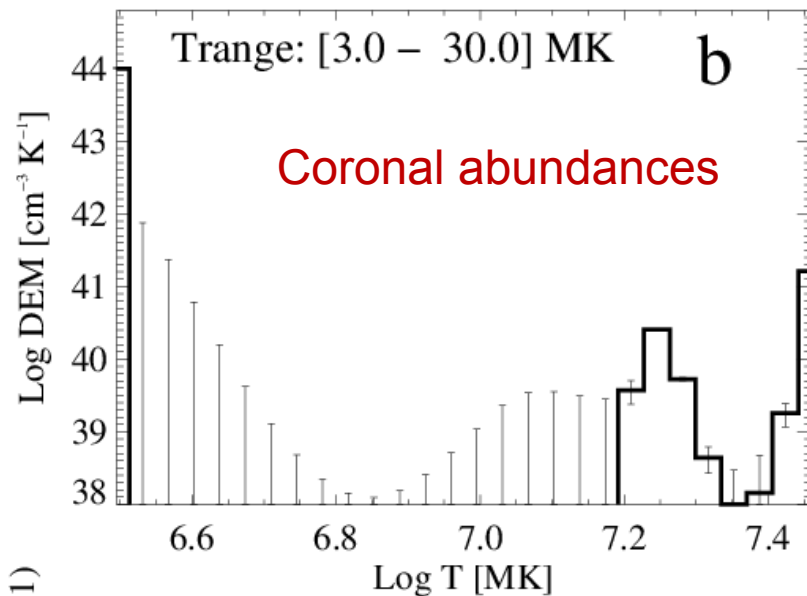
# Concluding remarks

- DEM distributions have been calculated using absolutely calibrated RESIK spectra. 15 spectral bands are identified in the range  $3.3 \text{ \AA} \div 6.1 \text{ \AA}$  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  $T < 9 \text{ MK}$  (probably related to the non-flaring active region) and a hotter one  $T > 9 \text{ MK}$  (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  $10^{11} \text{ cm}^{-3}$  near the flare peak.

**THANK YOU**

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

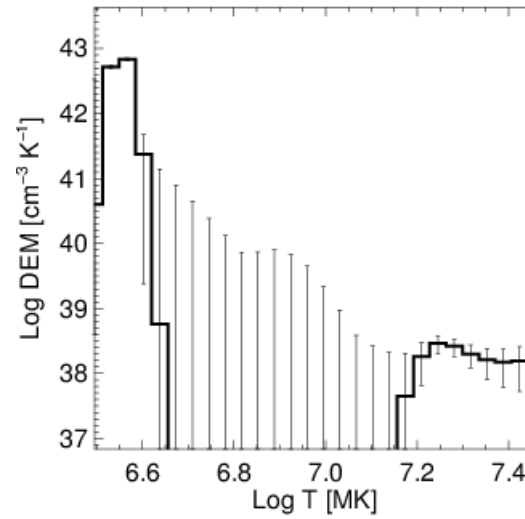
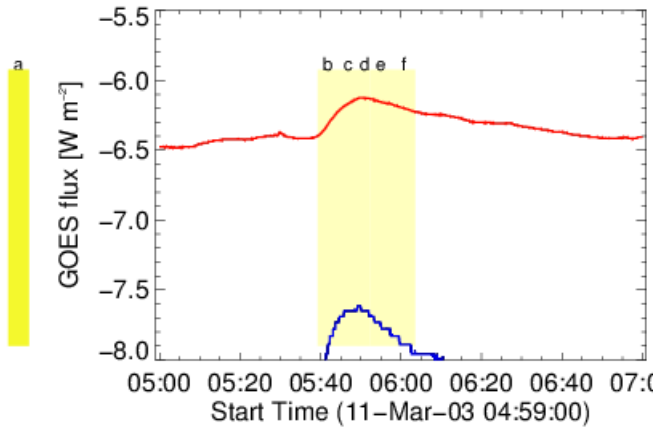
**With identical set of input fluxes, the inversion outcomes are quite different for particular patterns of plasma composition**



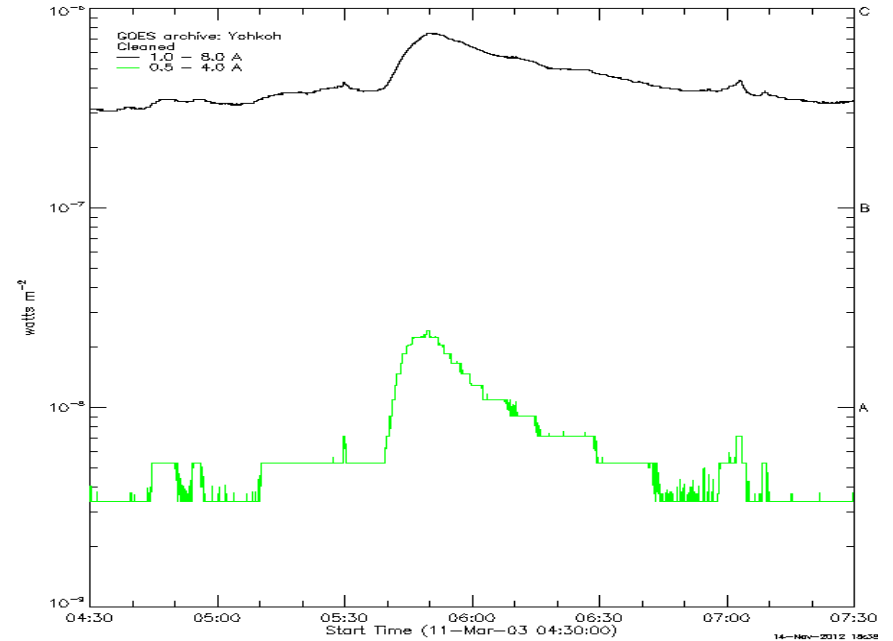
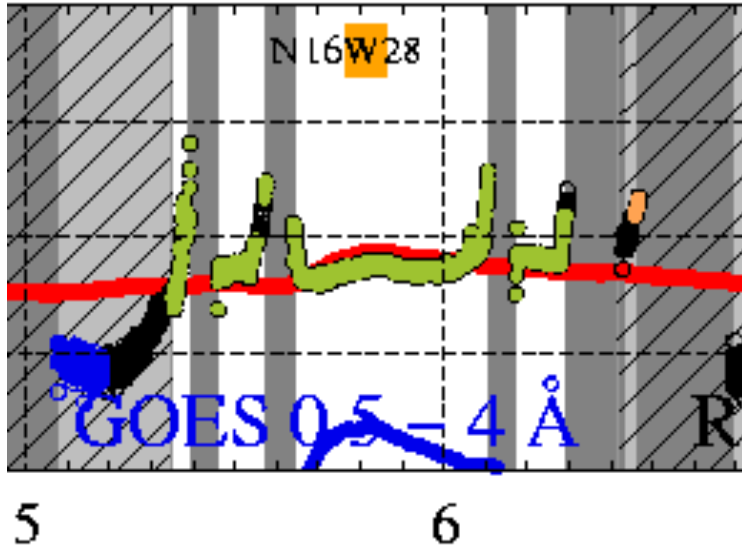
For the set of **coronal** and **photospheric** composition patterns the ratios of observed and DEM-predicted fluxes in individual spectral bands exceed **15%** and **20%** respectively. Overall inversion convergence is worse, if at all observed.

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 for active region ?



# SOL2003-03-11T05:50 B7.3



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

# DEM & RHESSI

