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Multitemperature analysis of solar flare observed on 2003 March 29

Anna Kepa[1], **Barbara Sylwester**[1], **Janusz Sylwester**[1], **Marek Siarkowski**[1], **Tomasz Mrozek**[1, 2], **Magdalena Gryciuk**[1, 2]

[1]Space Research Centre Polish Academy of Sciences, Solar Physics Division, Wroclaw, Poland

[2]Astronomical Institute, University of Wroclaw, Wroclaw, Poland.

We present results of multitemperature analysis of *GOES* C7.2 class flare observed on **2003 March 29**. This event occurred close to the centre of the solar disk (S12W14, maximum at 10:15 UT) and had two maxima in X-rays. We have performed analysis of physical parameters characterizing evolution of conditions in the flaring plasma. The temperature diagnostics have been carried out using the differential emission measure (DEM) approach based on the soft X-ray spectra collected by RESIK Bragg spectrometer. Analysis of data obtained by *RHESSI* provided opportunity to estimate the volume and thus calculating the density of hot flaring plasma.

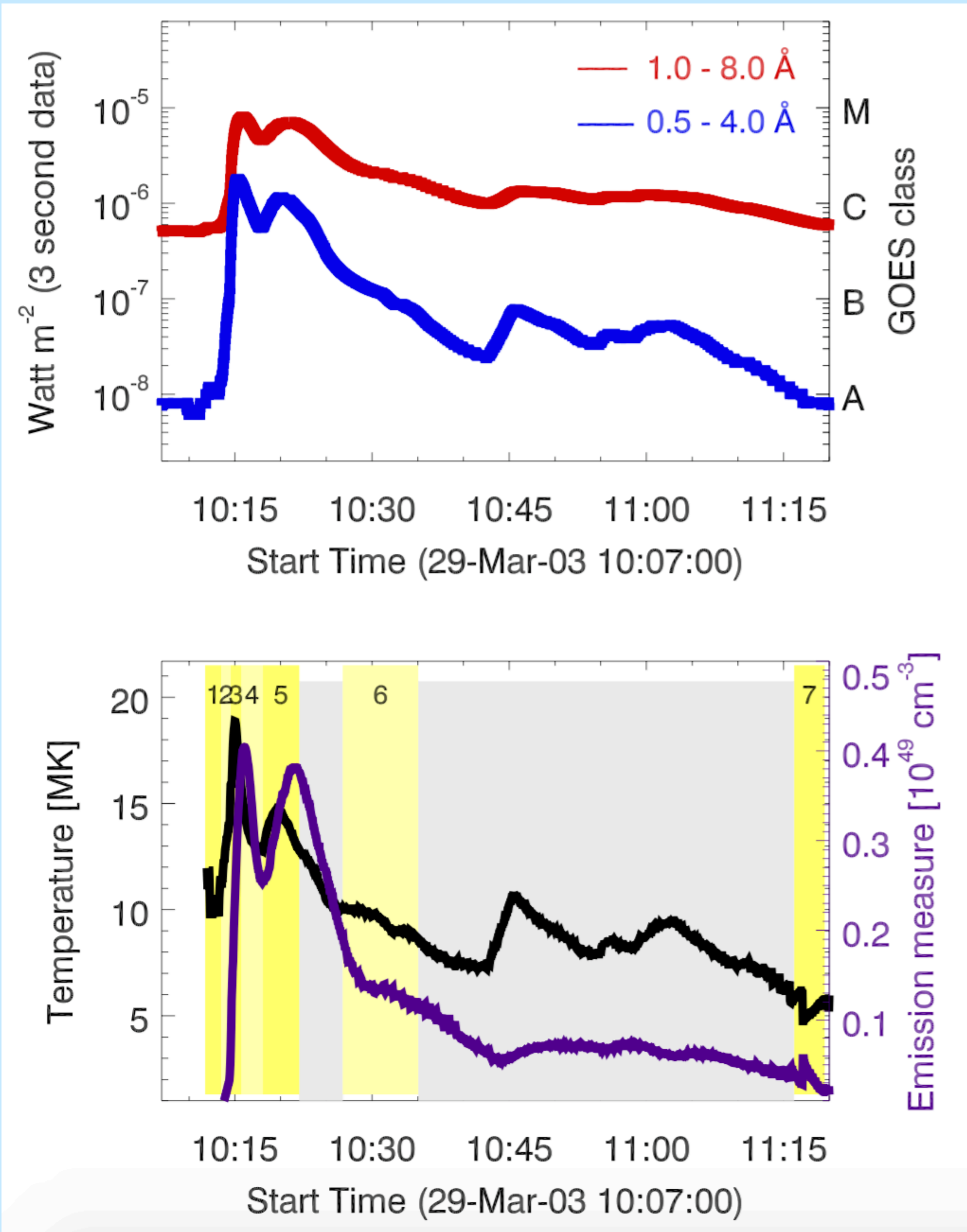

Fig.1 *GOES* light curves (top panel) and temperature and emission measure time variations calculated using isothermal aproximation for the SOL2003-03-29T10:15 flare. The seven numbers on lower panel (yellow stripes) denote intervals over which RESIK spectra were integrated for DEM analysis (detailed time integration of the RESIK spectra are shown in **Fig. 3**). The grey strip indicates a passage through a polar van Allen radiation belt when the RESIK high-voltages were turned off and no observations were made.

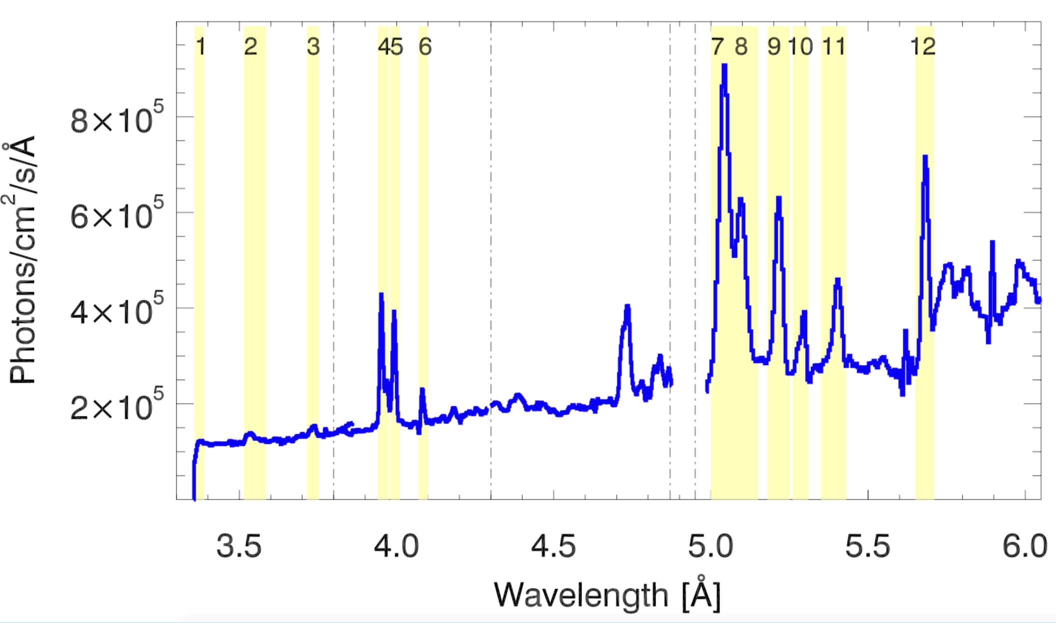

Fig.2 Average RESIK spectrum (integrated over 24 min) for SOL2003-03-29T10:15 flare. The lines used in the analysis are marked. See the Table for the details. The dashed lines indicate the four RESIK channels bands. Unfortunately, due to technical problems during this flare, channel 3 data are not reliable to the analysis for DEM calculations.

Nr	Wavelength range [Å]	Main line
1	3.358 - 3.388	Ar XVII 3p
2	3.515 - 3.585	K XVIII (w)
3	3.715 - 3.754	Ar XVIII 2p
4	3.940 - 3.975	Ar XVII (w)
5	3.980 - 4.010	Ar XVII (z)
6	4.070 - 4.100	S XV 4p
7	5.000 - 5.075	S XV 2p (w)
8	5.075 - 5.150	S XV 2p (z)
9	5.180 - 5.250	Si XIV 3p
10	5.260 - 5.310	Si XIII 5p
11	5.350 - 5.430	Si XIII 4p
12	5.650 - 5.710	Si XIII 3p

Table Spectral bands used to calculate the DEM distributions.

What was done

RESIK observations

We selected 7 time intervals. For each one we calculated the mean spectrum and fluxes in 12 sets of wavelength ranges (see the Table). Additionally to avoid the contribution of non-flaring plasma, the preflare X-ray fluxes have been subtracted.

DEM calculations

DEM (**$\varphi(T)$**) determinations were made using Adaptive Differential Evolution method (genetic algorithm). Starting from randomly chosen initial populations of different DEMs a new generation of DEMs is produced by crossover and mutations. Our population had 100 individual DEM distributions or 'chromosome'. Each chromosome consists of 100 gens – they correspond to DEM values for 100 temperatures in the range from 2 to 30 MK.

Process of breeding (and multiplication) of the whole population is controlled by assumed fitness criterion based on the value of observed to calculated fluxes. Predicted flux F_i was calculated using the formula:

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

where: f_i is emission function calculable from atomic excitation theory for chosen spectral intervals i and A_i represents the assumed abundance of an element contributing to the flux of a particular line or spectral interval. For chlorine abundance we adopted A_{Cl}=5.62*10^{-7}. For silicon, sulfur, argon, and potassium we used abundances calculated using AbuOpt method from multithermal assumption (Sylwester et al. 2015). We assumed A_{Si}=2.618*10^{-5}, A_S=7.413*10^{-6}, A_{Ar}=3.083*10^{-6}, A_K=6.067*10^{-7}. For other elements we adopted abundances called as "sun_coronal_ext.abud" (available in the Chianti package). The process of evolution was stopped after 6000 generations, when the convergence became very slow. The minimum χ^2 values were in range 1.5-2.3. The evolution process was repeated 10 times, each time starting from a new random population. Obtained DEM distributions are presented in **Fig. 3** (left column). For the rise and maximum phase of this flare the hard X-ray images from *RHESSI* were available. From this data we estimated volumes (spherical shape was assumed). The spatial dimensions combined with the total emission measure of the hotter component allowed us to estimate the electron density.

Fig.3 The sequence of DEM distributions, RESIK spectra and *TRACE* images of 171 Å taken in selected RESIK interval times. Each row corresponds to one time interval. In the middle panel the RESIK observed spectra are presented in blue. The synthetic spectra obtained from corresponding DEM distribution are plotted in black.

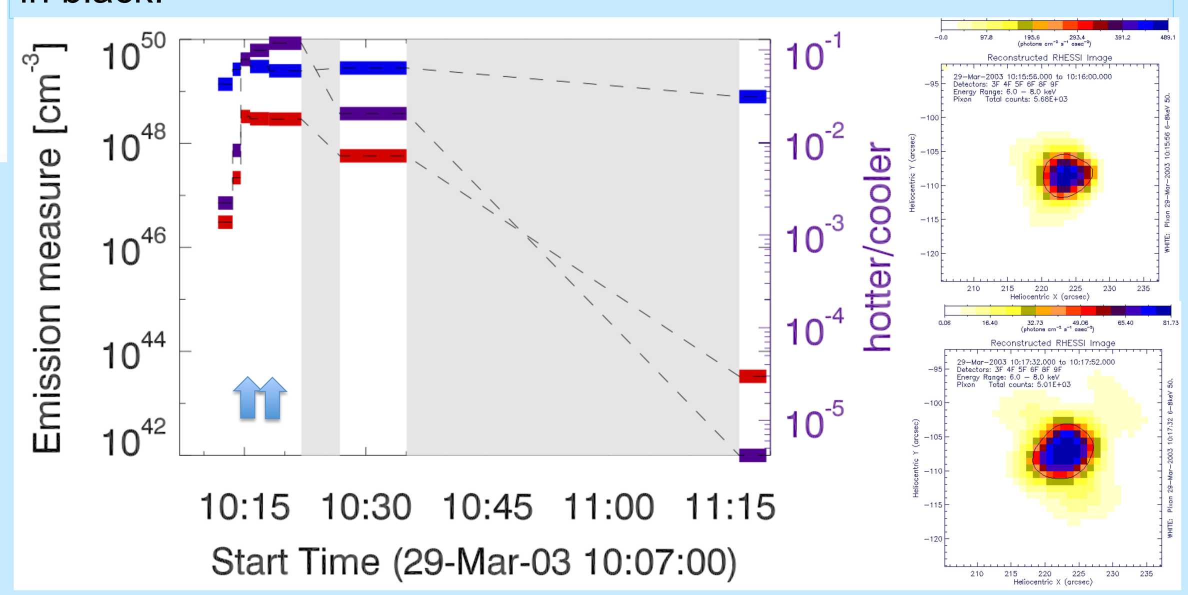

Fig.4 Left: The time evolution of the total emission measure for the cooler (3-10 MK, in blue) and hotter (12-30 MK, in red) plasma component. The purple line represents the ratio of hotter and cooler plasma component. **Right:** *RHESSI* images obtained with the PIXON algorithm in the energy range 6 – 8 keV. The times correspond to *RHESSI* images are marked (on left) by arrows.

Conclusions

For the first time we present the DEM distributions calculated using the genetic algorithm (Adaptive Differential Evolution method). Our DEM distributions are two components, which is consistent with previous results obtained using Withbroe-Sylwester method. The cooler component corresponds to plasma from 3 to 10 MK, hotter conforms the temperature range 12 − 25 MK. The volumes (estimated from RHESSI data) changed from 6.1×10^{24}cm^3 to 3.18×10^{25} cm^3. This gives the electron density values for the hot plasma from 1.7×10^{11} cm^{-3} to 4.1×10^{11} cm^{-3}.

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