Multitemperature analysis of solar flare observed on 2003 March 29

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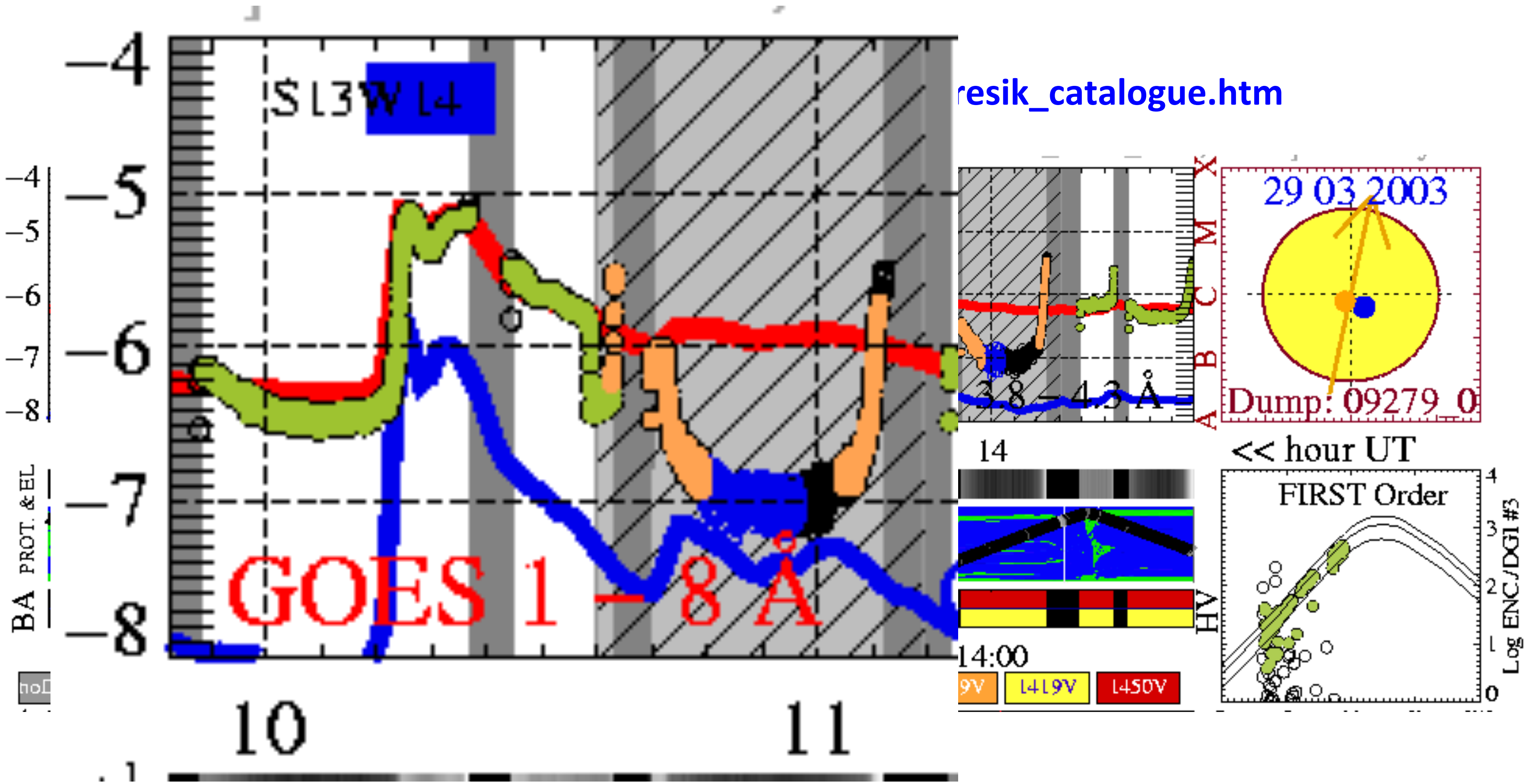
Abstract

We present results of multitemperature analysis of GOES C7.2 class flare SOL2003- 03-29T10:15. This event occurred close to the centre of the solar disk and had two maxima in soft 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 and thermal energy content of hot flaring plasma.

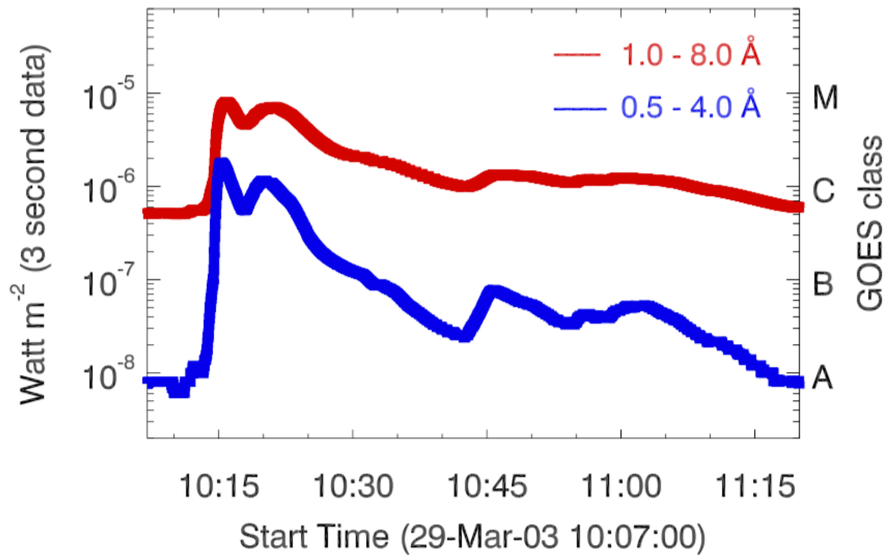
Observations



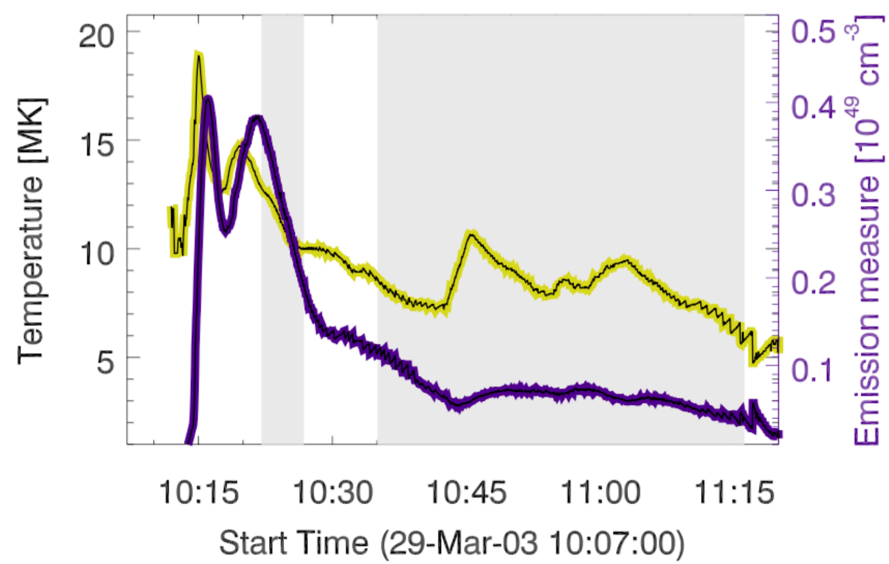
T_{Max} ~ 10:15 UT, GOES class C7.2 , S12W14

Isothermal aproximation

Temperatures (Te) and emission measures (EM) of the plasma were estimated using GOES 1−8 Å and 0.5−4 Å fluxes and the filter-ratio method proposed by Thomas et al. (1985) and updated by White et al. (2005).



$$Te_{MAX} = 18.9 \text{ MK}$$
$$EM_{MAX} = 4 * 10^{48} \text{ cm}^{-3}$$



Multitemperature analysis

Multithermal analysis = Differential emission measure (DEM)

$$\varphi(T_e) = N_e^2 \frac{dV}{dT_e}$$

N_e - electron density,
V - plasma volume,
T_e - temperature

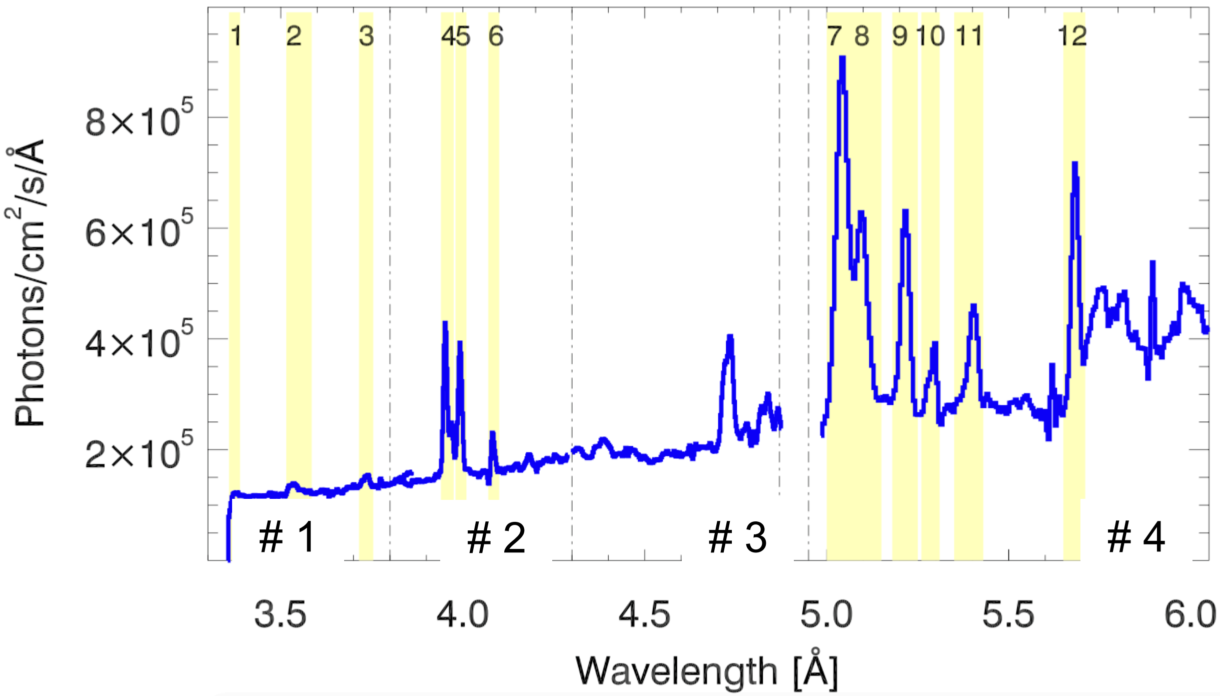
flux in appropriate spectral line/band i (i= 1, 2, 3, … N)

$$F_i = A_i \int_0^\infty f_i(T_e)\varphi(T_e)\,dT_e$$

abundance of an element contributing to the flux of a particular line or spectral interval

emission function

RESIK data



Average RESIK spectrum (integrated over 24). The dashed lines limit the four RESIK channels bands. Unfortunately, due to technical problems during this flare, channel 3 data are not reliable for the analysis for DEM calculations.

For silicon, sulfur, argon, and potassium we used abundances calculated using the multithermal assumption (AbuOpt method; Sylwester et al., 2015).

We assumed $A_{Si} = 2.618 * 10^{-5}$, $A_S = 7.413 * 10^{-6}$, $A_{Ar} = 3.083 * 10^{-6}$, $A_K = 6.067 * 10^{-7}$.

No.	Wavelength range [Å]	Main line	Channel
1	3.358 - 3.388	Ar XVII 3p	1
2	3.515 - 3.585	K XVIII (w)	1
3	3.715 - 3.754	Ar XVIII 2p	1
4	3.940 - 3.975	Ar XVII (w)	2
5	3.980 - 4.010	Ar XVII (z)	2
6	4.070 - 4.100	S XV 4p	2
7	5.000 - 5.075	S XV 2p (w)	4
8	5.075 - 5.150	S XV 2p (z)	4
9	5.180 - 5.250	Si XIV 3p	4
10	5.260 - 5.310	Si XIII 5p	4
11	5.350 - 5.430	Si XIII 4p	4
12	5.650 - 5.710	Si XIII 3p	4

Differential evolution

Differential evolution (Storn & Price, 1995;, 1997) is simple but powerful evolutionary algorithm for global optimization.

The differential evolution (DE) works with two population P and Q of the same size N.

generate $P = (\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_N)$; ($N$ points in D at random)
repeat
    for $i := 1$ **to** N **do**
        compute a mutant vector $\mathbf{u}$;
        create a trial point $\mathbf{y}$ by the crossover of $\mathbf{u}$ and $\mathbf{x}_i$;
        if $f(\mathbf{y}) < f(\mathbf{x}_i)$ **then** insert $\mathbf{y}$ into Q
                        else insert $\mathbf{x}_i$ into Q
        endif;
    endfor;
    $P := Q$;
until stopping condition;

A new trial point y is composed of the current point x_i of old population and the point u obtained by using mutation. If $f(y) < f(x_i)$ the point y is inserted into the new population Q instead of x_i. After completion of the new population Q the old population P is replaced by Q and the search continues until stopping condition is fulfilled.

DEM calculation

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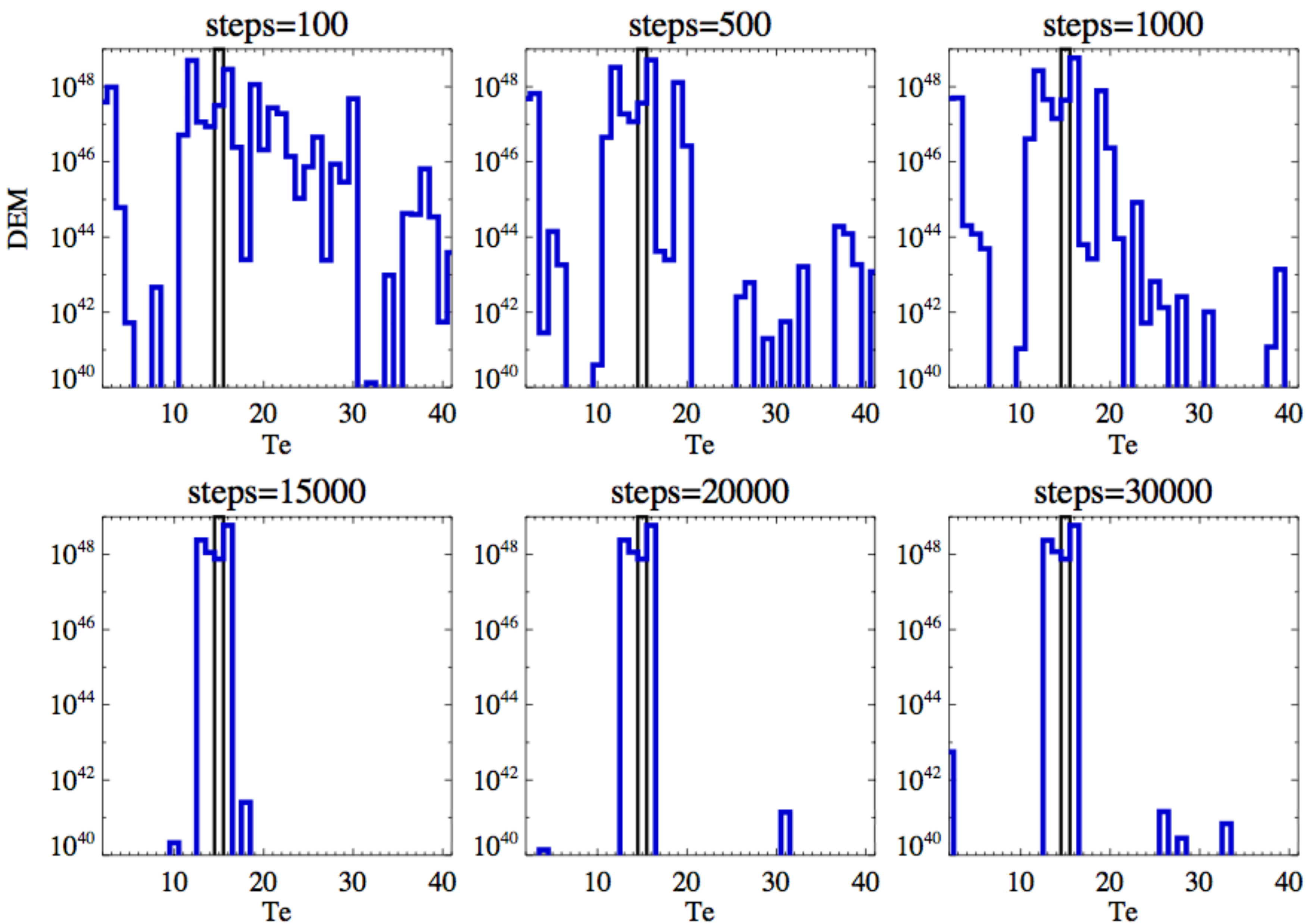
- Starting from randomly chosen initial populations of different DEMs a new generation of DEMs is produced by crossover and mutations.

- Our population had 100 individual DEM distributions or ’chromosomes’.

- Each chromosome consists of 100 gens correspond to DEM values for 100 temperatures in the range from 2 to 30 MK.

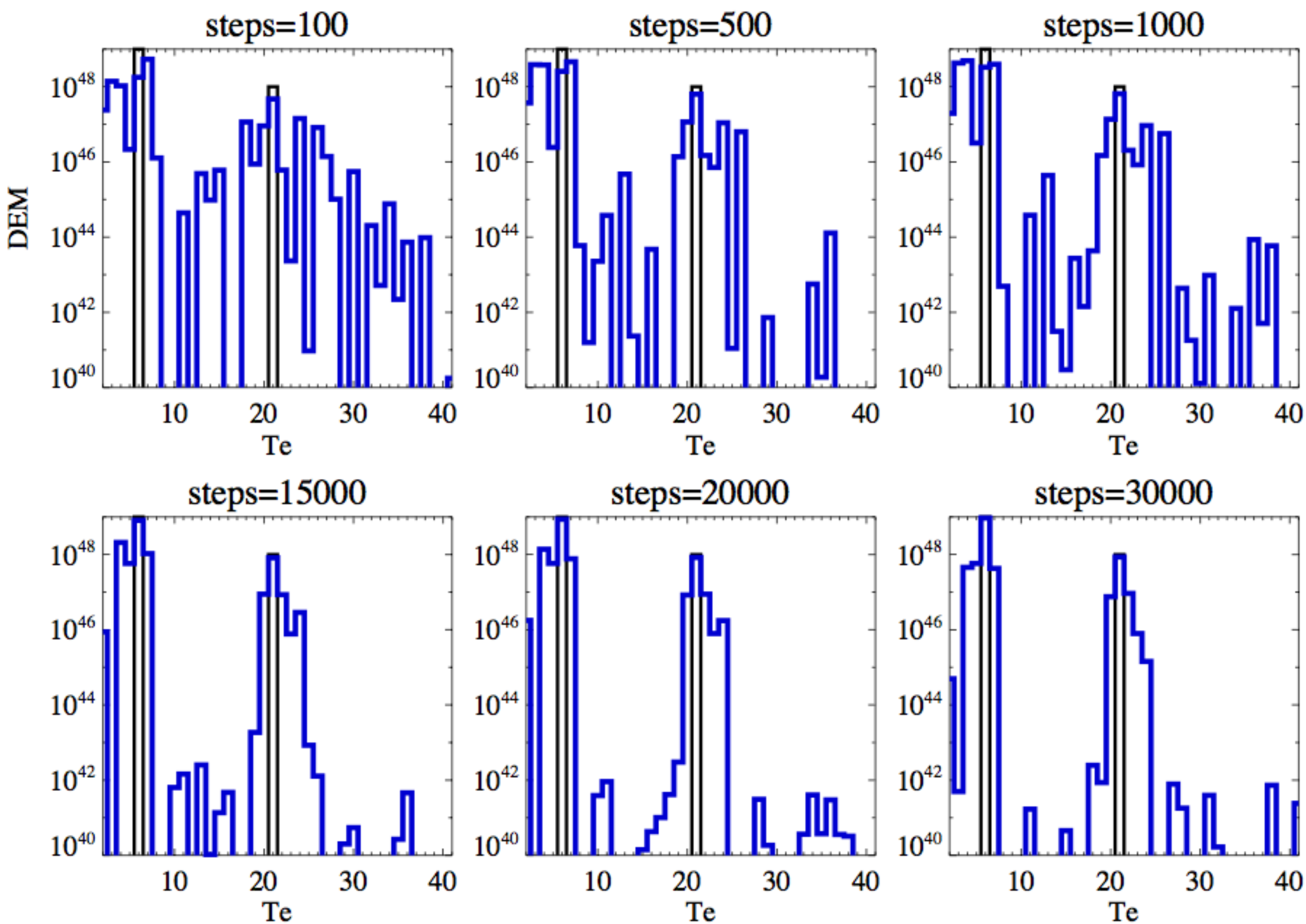
- Process of breeding (and multiplication) of the whole population is controlled by assumed fitness criterion based on the values of observed to calculated fluxes.

Tests



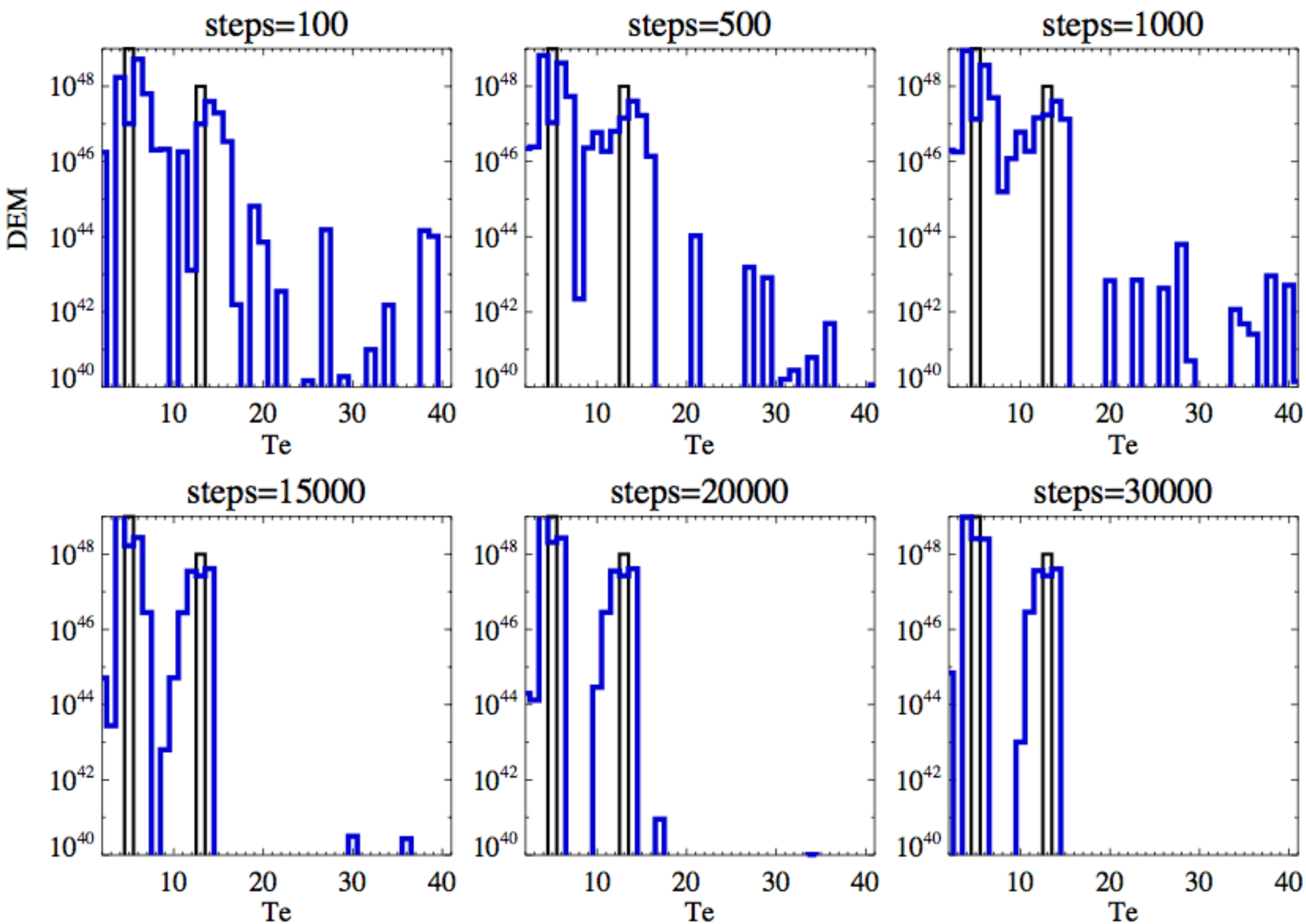
steps=100
steps=500
steps=1000
steps=15000
steps=20000
steps=30000
DEM
Te
10
20
30
40
10^{40}
10^{42}
10^{44}
10^{46}
10^{48}

Tests



steps=100
steps=500
steps=1000
steps=15000
steps=20000
steps=30000
DEM
Te
10^{40}
10^{42}
10^{44}
10^{46}
10^{48}
10
20
30
40

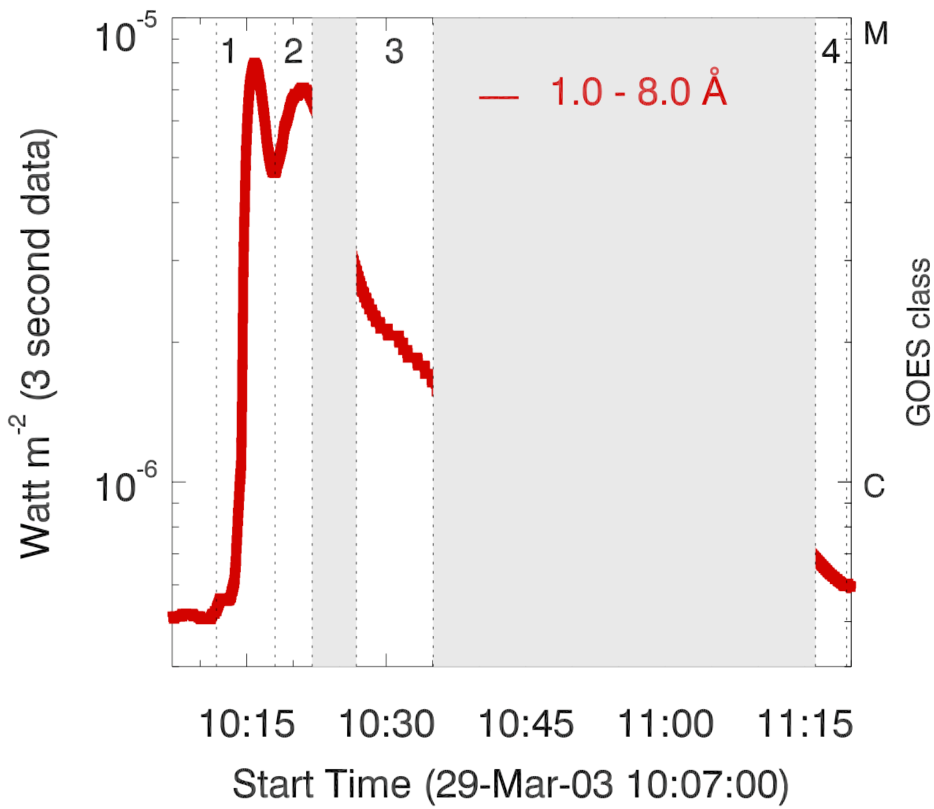
Tests


steps=100
steps=500
steps=1000
steps=15000
steps=20000
steps=30000
DEM
10^{48}
10^{46}
10^{44}
10^{42}
10^{40}
10
20
30
40
Te

RESIK data

For four selected time intervals (corresponding to different flares) we calculated the mean spectrum and fluxes in N = 12 wavelength ranges.

To avoid the contribution of non-flaring plasma, the preflare X-ray fluxes have been subtracted.



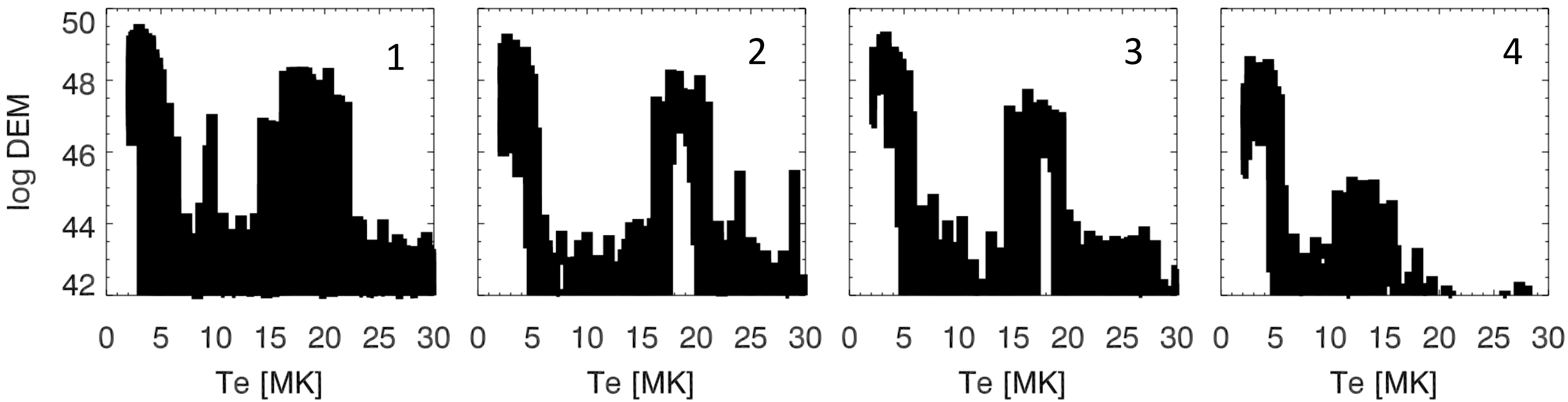
The four numbers denote intervals over which RESIK spectra were integrated for DEM analysis.

The grey strips indicate time intervals of passages through a polar van Allen radiation belt when the RESIK high-voltages were turned off and no observations were made.

DEM

The process of evolution was stopped after 6000 generations, when the convergence became very slow. The minimum χ^2 values were in the range 1.5-2.3.

The evolution process was repeated 10 times, each time starting from a new random population.

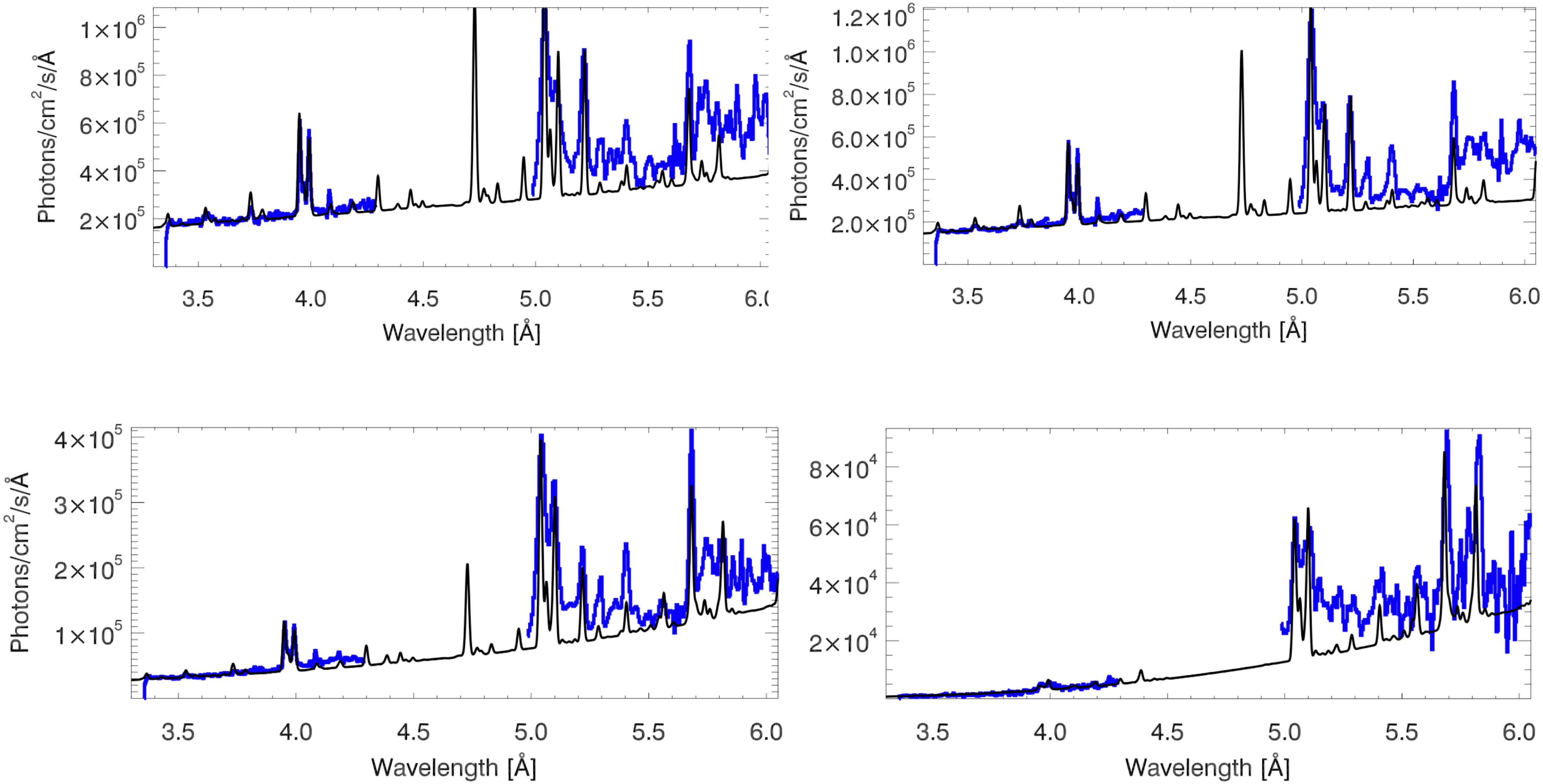


DEM distributions are two components, which is consistent with previous results obtained using Withbroe-Sylwester method. The cooler component corresponds to plasma from 3 MK to 10 MK, hotter conforms the temperature range 12 - 25 MK.

Spectra comparison

RESIK observed spectra

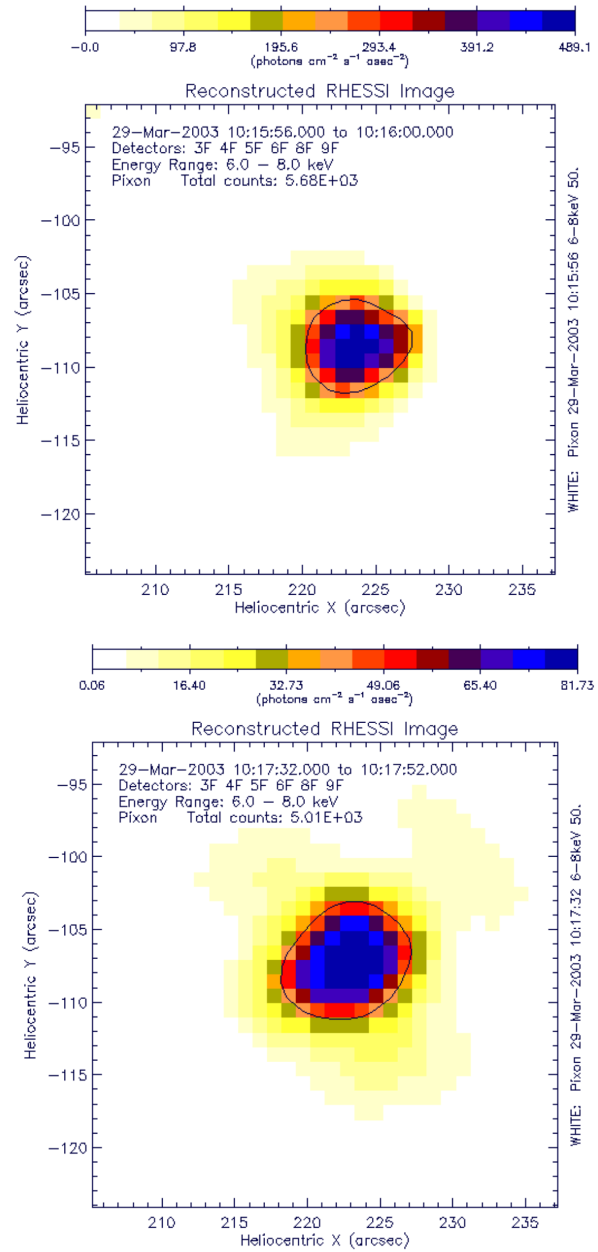
synthetic spectra obtained from corresponding DEM distribution



The volumes (estimated from *RHESSI* data, spherical shape was assumed) changed from **6.1×10^{24} cm^3 to 3.2×10^{25} cm^3** .

The averaga volume = **$1.9*10^{25}$ cm^3**

This leads to the following values of **electron density** and **thermal energy content for the hot component** of the plasma**: $2.9 * 10^{11}$ cm^{-3}** as **$4.11 * 10^{28}$ erg**.



RHESSI images obtained with the PIXON algorithm in the energy range 6 – 8 keV.

Summary

- For the first time we present the DEM distributions calculated using the 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 MK to 10 MK, hotter conforms the temperature range 12 - 25 MK.

- For the first flare the average volume (estimated from RHESSI data) is $1.9 \ast 10^{25}$ cm^3. This leads to the following values of electron density and thermal energy content for the hot component of the plasma: $2.9 \ast 10^{11}$ cm^{-3} as $4.11 \ast 10^{28}$ erg.

Thank you for your attention ☺