On the application of differental evolution to the analysis of X-ray spectra

Anna Kępa, Barbara Sylwester, Marek Siarkowski, Janusz Sylwester

Space Research Centre, Polish Academy of Sciences, Bartycka 18a, Warsaw

Solar Physics Division, Kopernika 11 Wrocław

This research has been done in the framework of the Polish National Science Centre grant No. 2017/25/B/ST9/01821

1. DEM, elemental abundances

$$\varphi(T_\mathrm{e}) = N_\mathrm{e}^2 \frac{\mathrm{d}V}{\mathrm{d}T_\mathrm{e}}$$

N_e - electron density

V - plasma volume

T_e - temperature

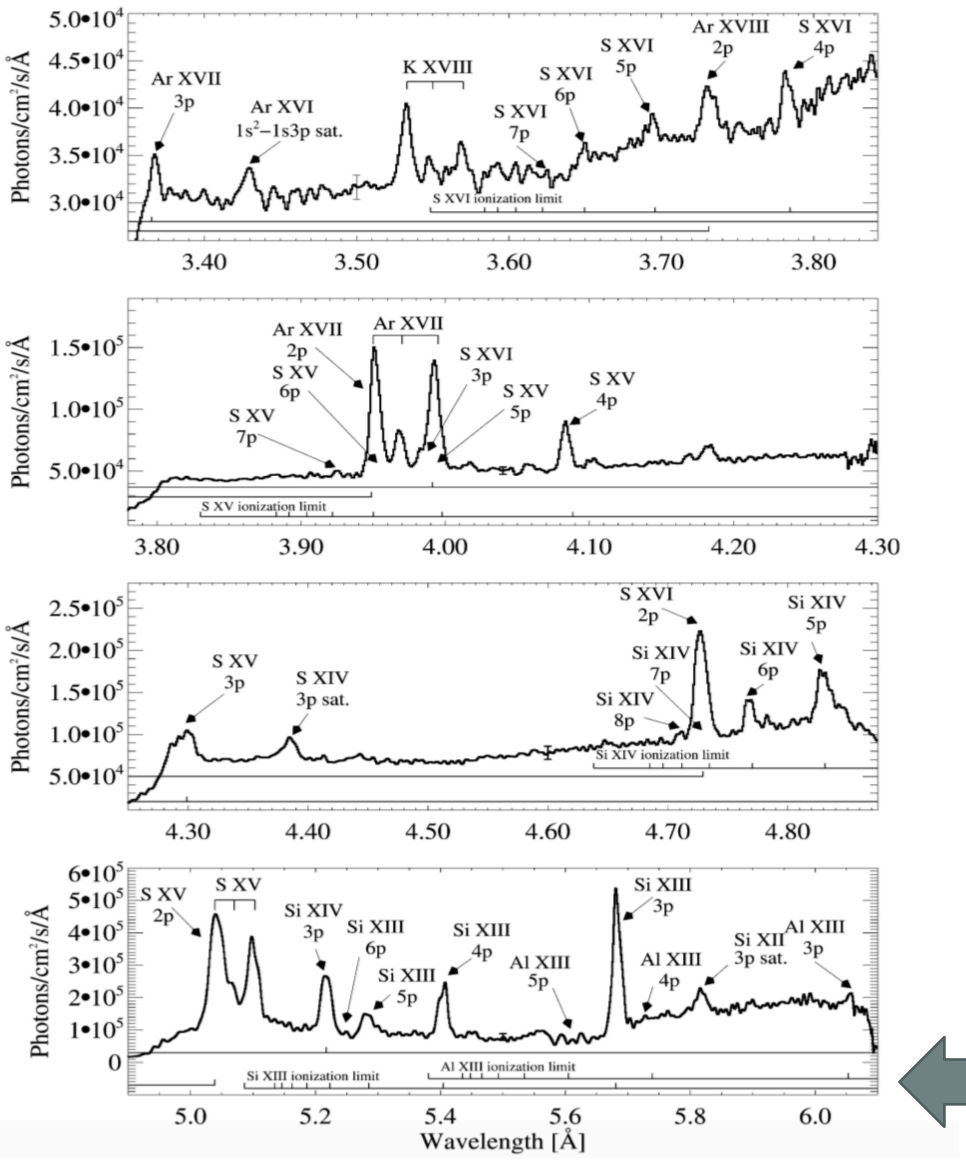
A_i - assumed abundance of an element

$f_i(T_\mathrm{e})$ - emission function

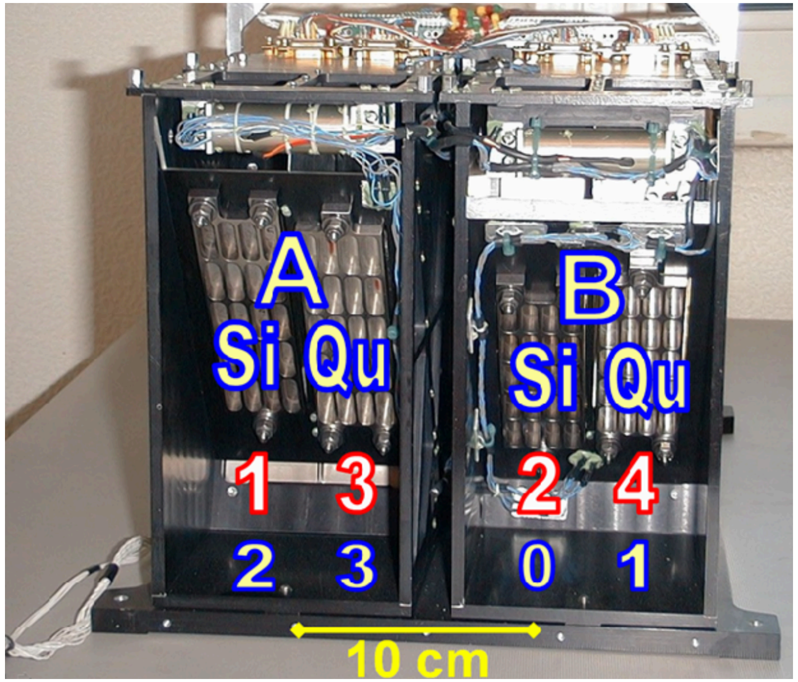
N - number of spectra bands

$$F_i = A_i \int_0^\infty f_i(T_\mathrm{e})\varphi(T_\mathrm{e})\,\mathrm{d}T_\mathrm{e} \quad i = 1, 2, \ldots N$$

1. X-ray spectra, RESIK spectrometer



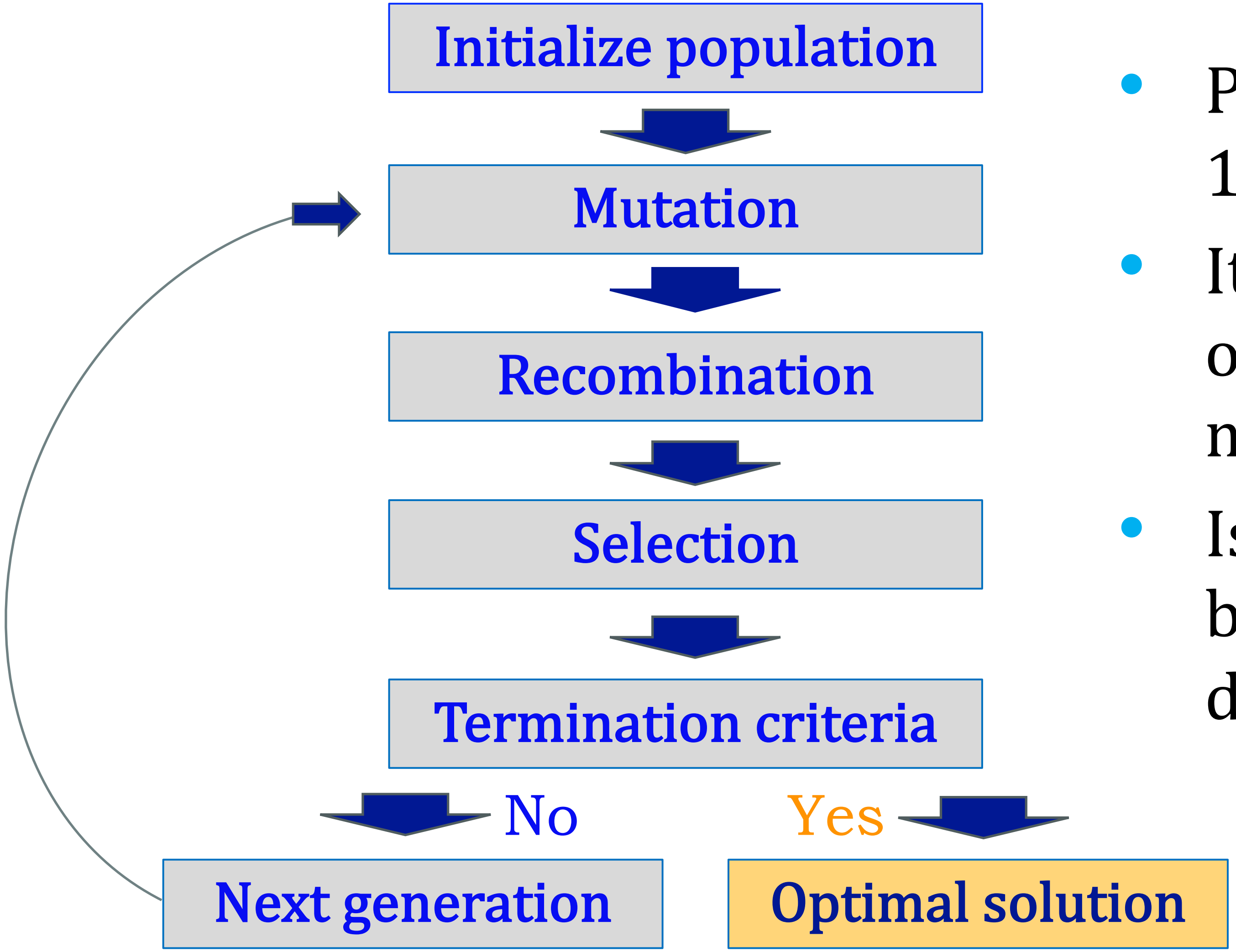
REntgenovsky Spektrometr s Izognutymi Kristalami instrument, consisting of two double-channel X-ray spectrometers, designed to observe solar active region and flare plasmas.



Mission : CORONAS-F
Operated: 2001 – 2003
Spectral range: 3.3 – 6.1 A

Average spectra observed by RESIK for 14 flares
(the total integration time amounts approximately to 9h)

2. Differential evolution (DE) method



- Proposed by Price and Storn in 1995
- It is a stochastic, population-based optimization algorithm for solving nonlinear optimization problem
- Is a very powerful algorithm for black-box optimization (also called derivative-free optimization).

3. Differential evolution (DE) method

1. Population

Abundances	DEM

1T

A_{Si}	A_S	A_{Ar}	A_K	T_1	$\varphi(T_1)$

2T

A_{Si}	A_S	A_{Ar}	A_K	T_1	$\varphi(T_1)$	T_2	$\varphi(T_2)$

abundances DEM

30T

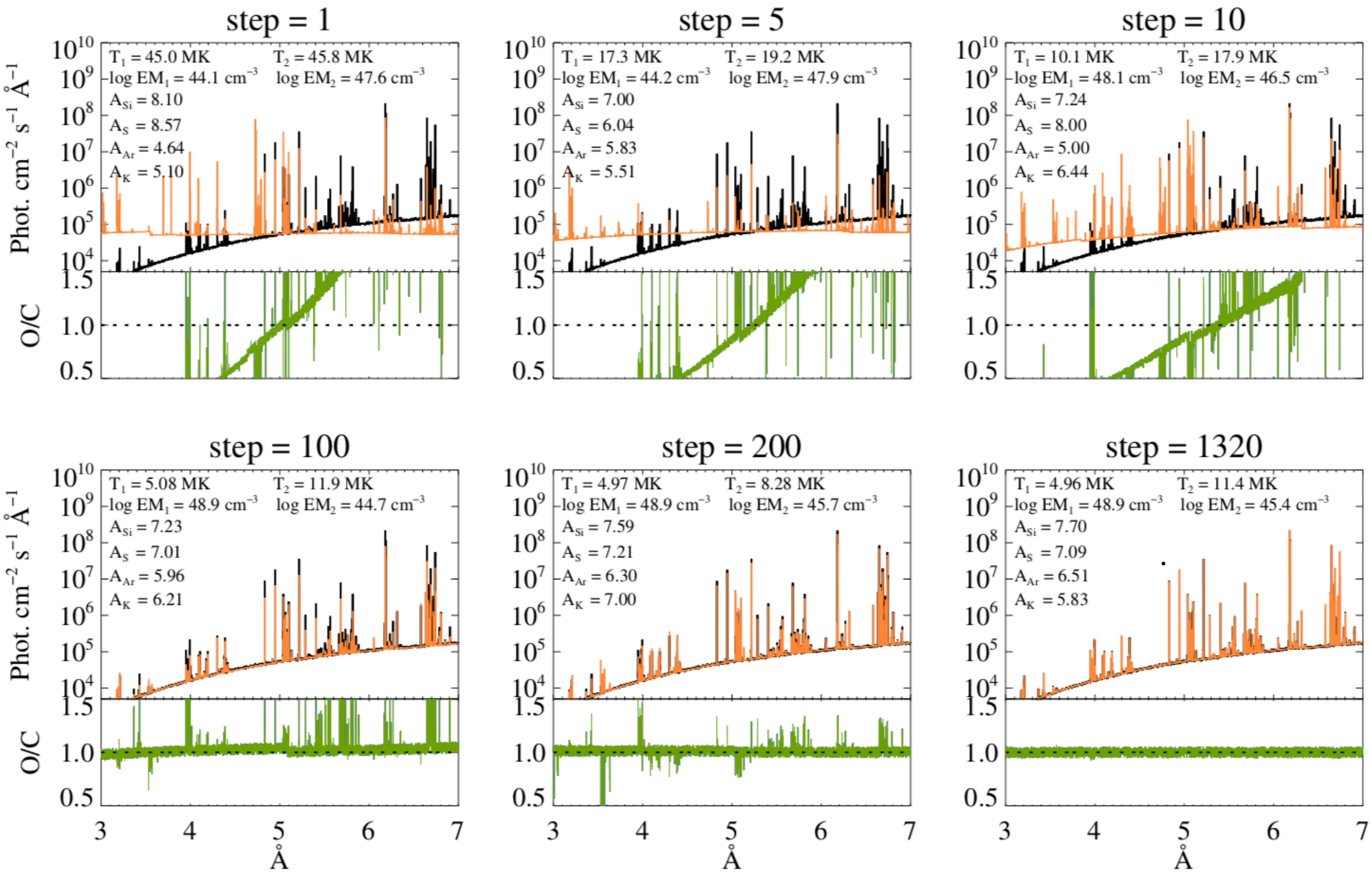
A_{Si}	A_S	A_{Ar}	A_K	$\varphi(T_1)$	$\varphi(T_2)$	$\varphi(T_3)$	...	$\varphi(T_2)$	$\varphi(T_N)$

abundances DEM

N=30

1MK – 30 MK, ΔT=1MK

4. Tests



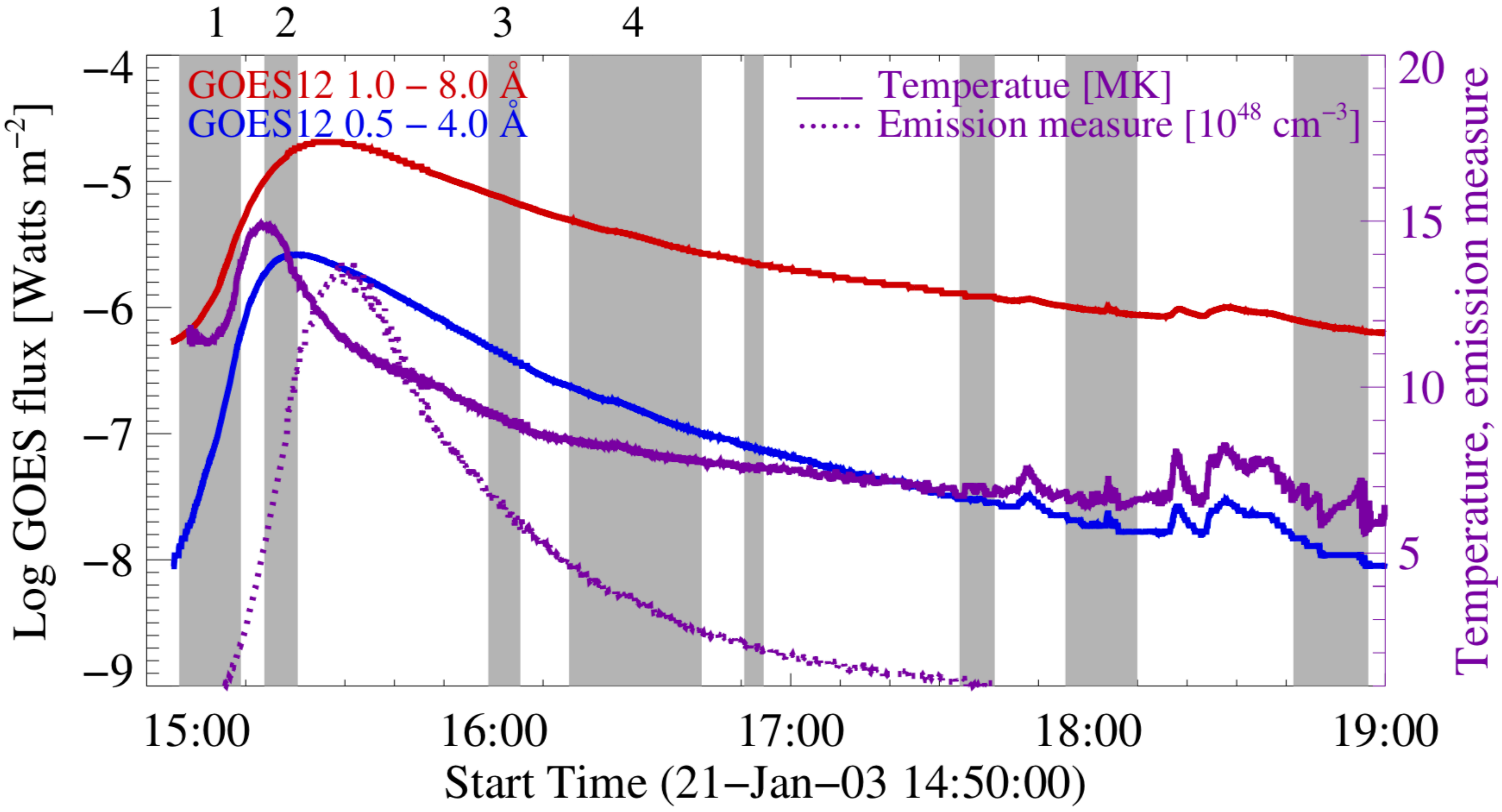
Model 2T

T_1=5 MK
EM_1=1x10^{49} cm^{-3}

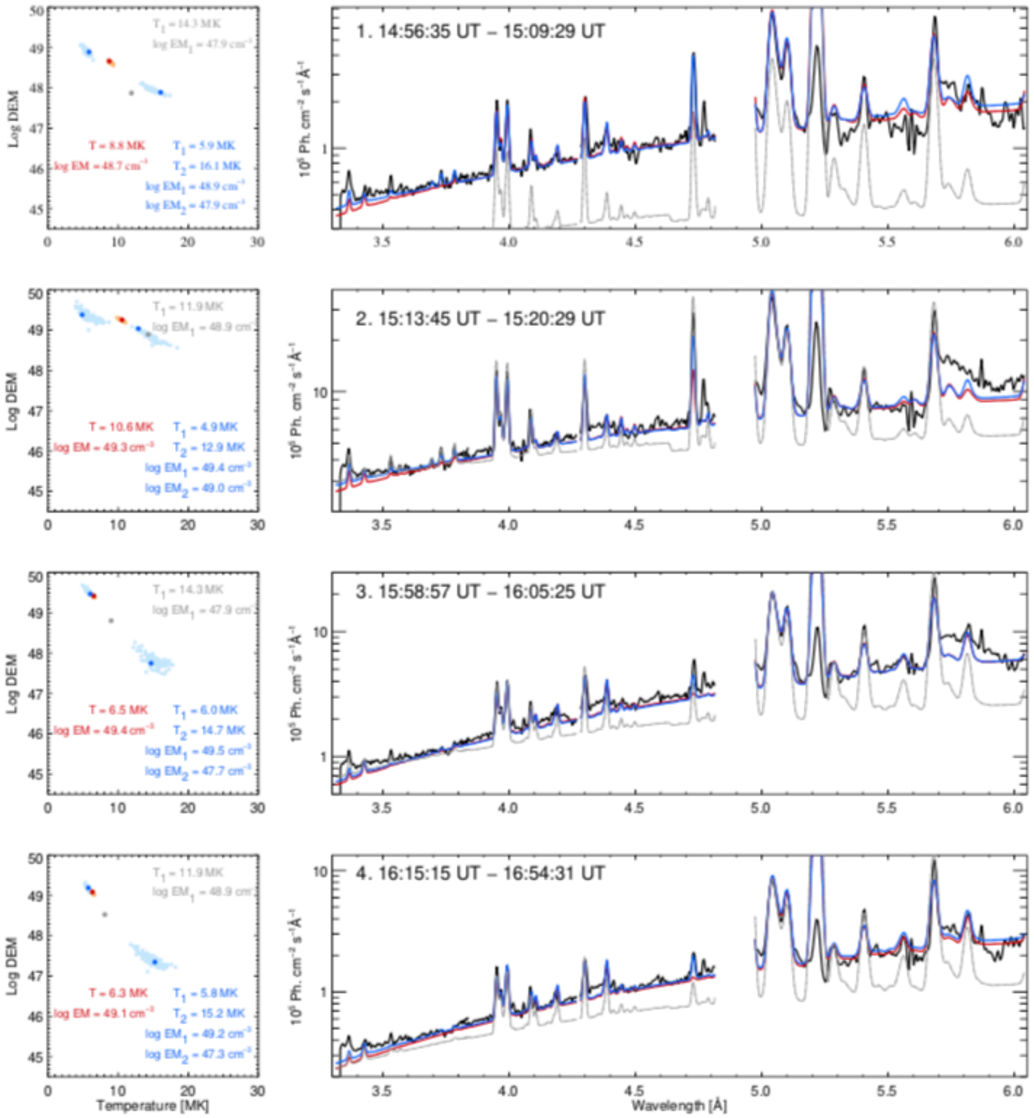
T_2=12 MK
EM_2=2x10^{45} cm^{-3}

Abu Si = 7.70
Abu S = 7.10
Abu Ar = 6.50
Abu K = 5.9

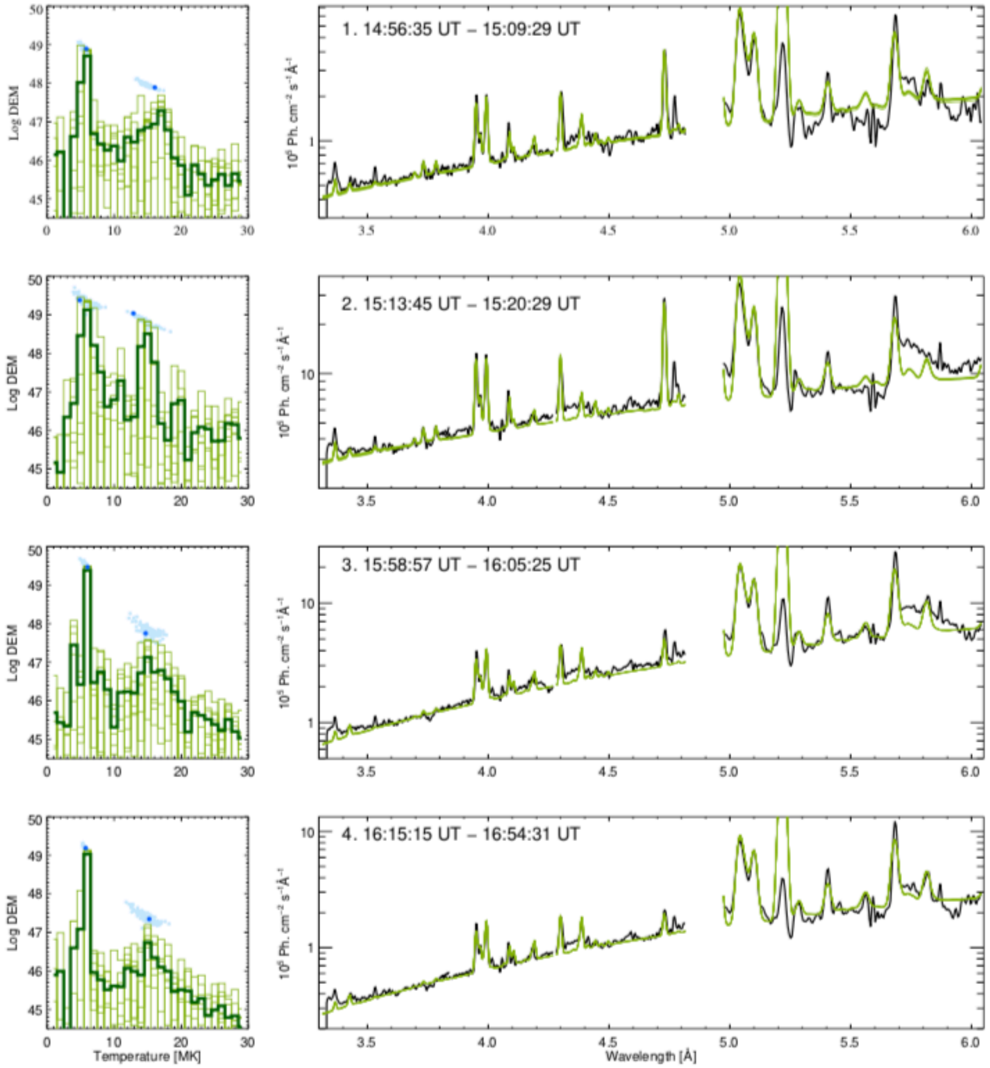
5. Observations



6. Results



1T, 2T, GOES



2T, 30T

6. Results

	A_{Si}	A_S	A_K	A_{Ar}
1. 14:56:35 UT - 15:09:01 UT	7.43 ±0.07 (1T)	6.99 ±0.05 (1T)	5.00 ±0.03 (1T)	6.37 ±0.05 (1T)
	7.51 ±0.07 (2T)	7.10 ±0.08 (2T)	5.04 ±0.22 (2T)	6.38 ±0.08 (2T)
	7.50±0.04 (30T)	7.10 ±0.02 (30T)	5.03 ±0.10 (30T)	6.40 ±0.01 (30T)
2. 15:13:45 UT - 15:20:29 UT	7.29 ±0.09 (1T)	6.90 ±0.05 (1T)	5.00 ±0.00 (1T)	6.37 ±0.05 (1T)
	7.40 ±0.15 (2T)	7.03 ±0.09 (2T)	5.10 ±0.29 (2T)	6.38 ±0.06 (2T)
	7.42±0.05 (30T)	7.05 ±0.02 (30T)	5.06 ±0.16 (30T)	6.38 ±0.01 (30T)
3. 15:58:57 UT - 16:05:25 UT	7.45 ±0.05 (1T)	7.01 ±0.03 (1T)	5.00 ±0.00 (1T)	6.40 ±0.06 (1T)
	7.50 ±0.05 (2T)	7.04 ±0.06 (2T)	5.07 ±0.21 (2T)	6.42 ±0.06 (2T)
	7.51±0.01 (30T)	7.05 ±0.01 (30T)	5.03 ±0.07 (30T)	6.42 ±0.01 (30T)
4. 16:15:15 UT - 16:42:01 UT	7.48 ±0.05 (1T)	7.02 ±0.04 (1T)	5.00 ±0.00 (1T)	6.40 ±0.07 (1T)
	7.50 ±0.07 (2T)	7.04 ±0.04 (2T)	5.07 ±0.33 (2T)	6.41 ±0.07 (2T)
	7.51±0.01 (30T)	7.05 ±0.01 (30T)	5.03 ±0.14 (30T)	6.41 ±0.02 (30T)

A_{si}=7.53, A_s=6.97, A_{Ar}=6.35 - elemental abundances obtained by Sylwester et al. (2015a)

7. Conclusions:

- The values of temperature and emission measure calculated based on GOES fluxes using isothermal model of plasma do not allow to reproduce RESIK spectra.
- This (most probably) indicate that coronal set of abundances used by goes ssw analysis package is not generally applicable for detailed analysis of every coronal source.
- The two-components model of plasma better describes RESIK observations then isothermal model (as expected).
-
- The values of the average temperatures and the total emission measure (30T model) are very similar to those obtained for the 2T model.
- The values of abundance for silicon, sulphur, and argon don’t change during flare evolution.
- Best fit DE abundance values are within uncertainties the same to these obtained by Sylwester et al. (2015a) for the same flare using different approach.
- It was not possible to determine the potassium abundance based the RESIK spectra used in this study (too small potassium line contribution).