S320.7.03

High-temperature solar flare plasma behaviour from crystal spectrometer observations

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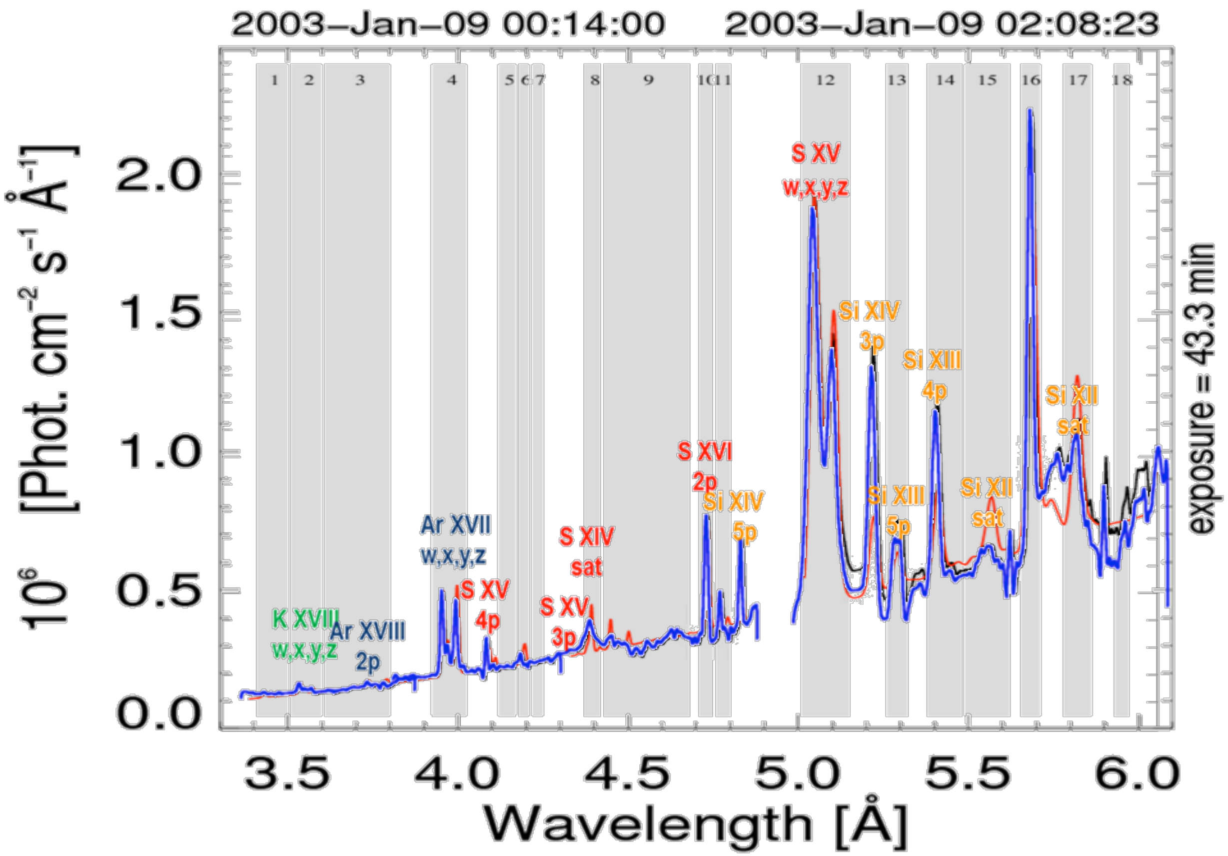
RESIK soft X-ray spectra analysis abundances in multitemperature approach



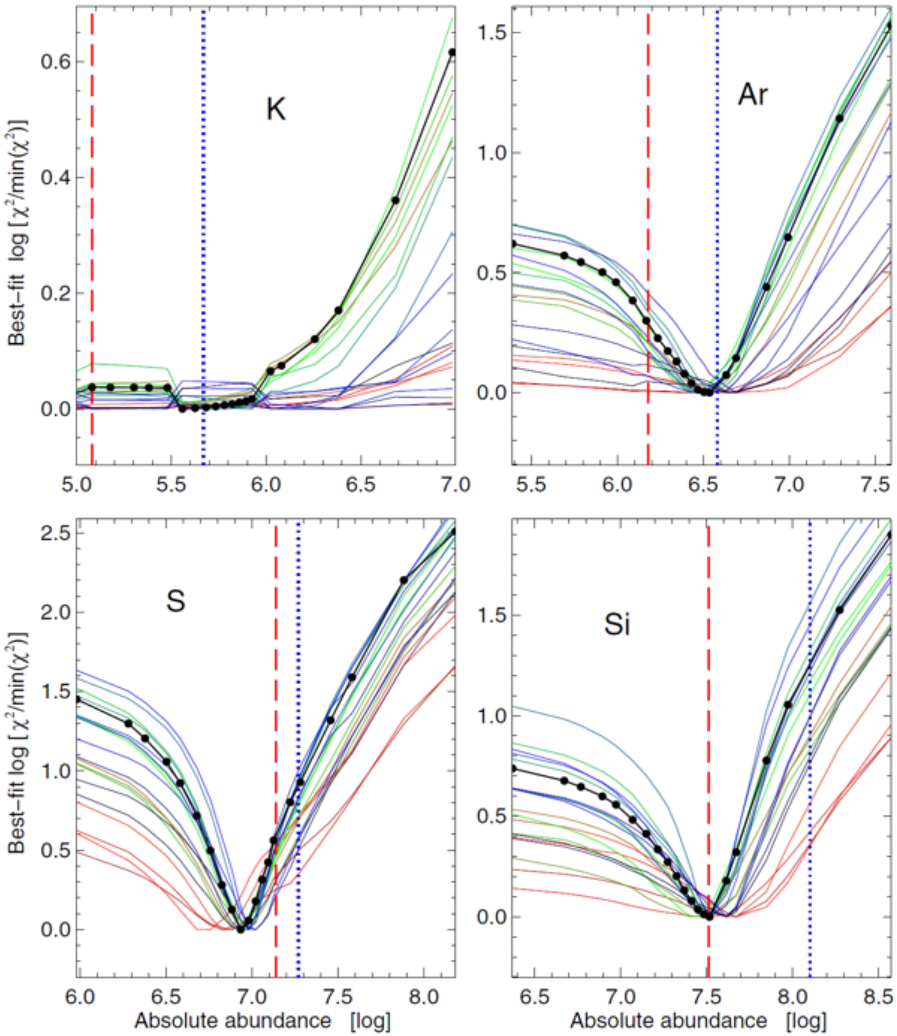
- 18 spectral intervals
- 4 elements (K, Ar, S, Si)
- **21** values of abundance for each element (0.1-16 times coronal value)
- Abundance corresponding to min. X^2 is the optimum one.

No.	Wavelength range (Å)	RESIK Channel	Emission features included
1	3.40 - 3.50	1	continuum
2	3.50 - 3.60	1	K XVIII triplet + sats.
3	3.60 - 3.80	1	continuum
4	3.915 - 4.025	2	Ar XVII triplet + sats.
5	4.11 - 4.17	2	continuum
6	4.17 - 4.21	2	S XV $1s^2 - 1s4p$ sats.
7	4.21 - 4.25	2	continuum
8	4.36 - 4.42	3	S XV d3 sats.
9	4.42 - 4.68	3	continuum
10	4.70 - 4.75	3	S XVI Lyα
11	4.75 - 4.80	3	S XV sats to S XVI Lyα
12	5.00 - 5.15	4	S XV triplet + sats.
13	5.25 - 5.32	4	Si XIII $1s^2 - 1s5p$
14	5.37 - 5.48	4	Si XIII $1s^2 - 1s4p$ + $5p$ sat.
15	5.48 - 5.62	4	Si XII $4p$ sats.
16	5.645 - 5.71	4	Si XIII $1s^2 - 1s3p$
17	5.77 - 5.86	4	Si XII $3p$ sat.
18	5.92 - 5.97	4	continuum

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

How it works for the element in question

The Astrophysical Journal, 787:122 (10pp), 2014 June 1



By changing the abundance of an investigated element, the other are kept constant to their "coronal values"

Theory spectra are generated every time and used in multi-T fitting exercise.

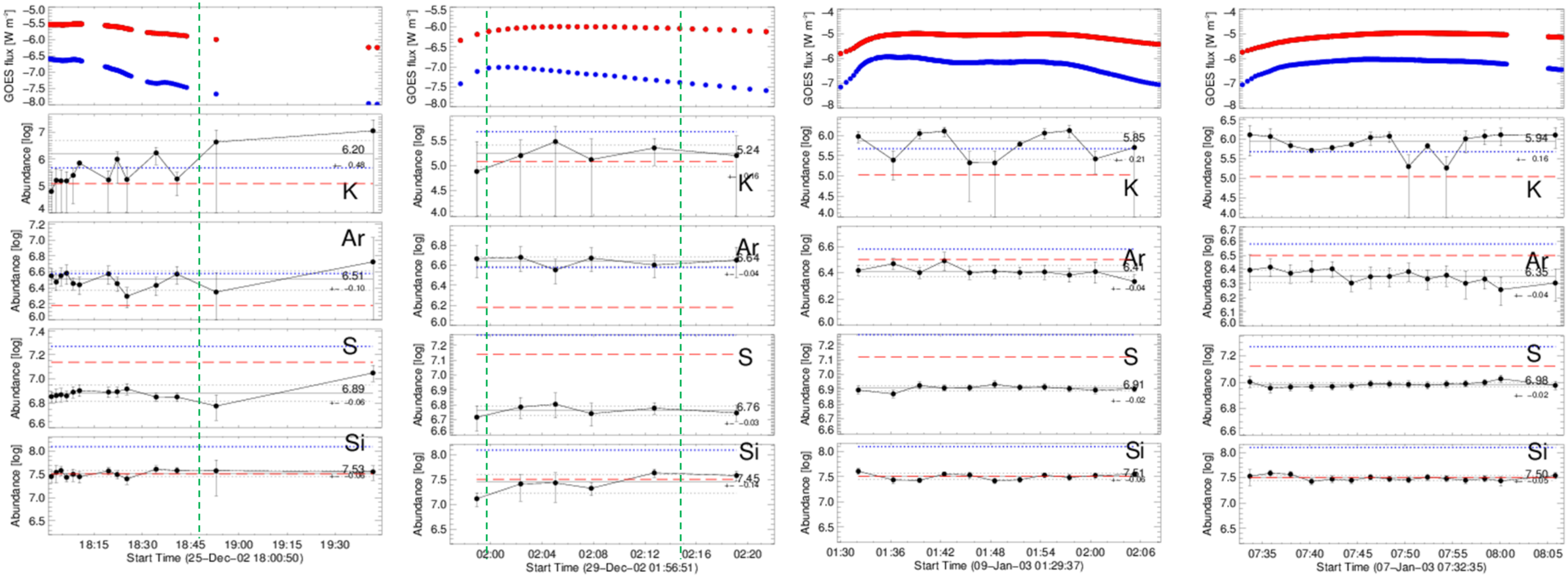
The quality of the fit is noted after 1000 iterations.

Plots are constructed showing dependence of the fit quality on abundance.

Sharp minimum is detected for elements with stronger lines.

Position of the minimum is established together with uncertainty

Examples of abundances determined for selected flares

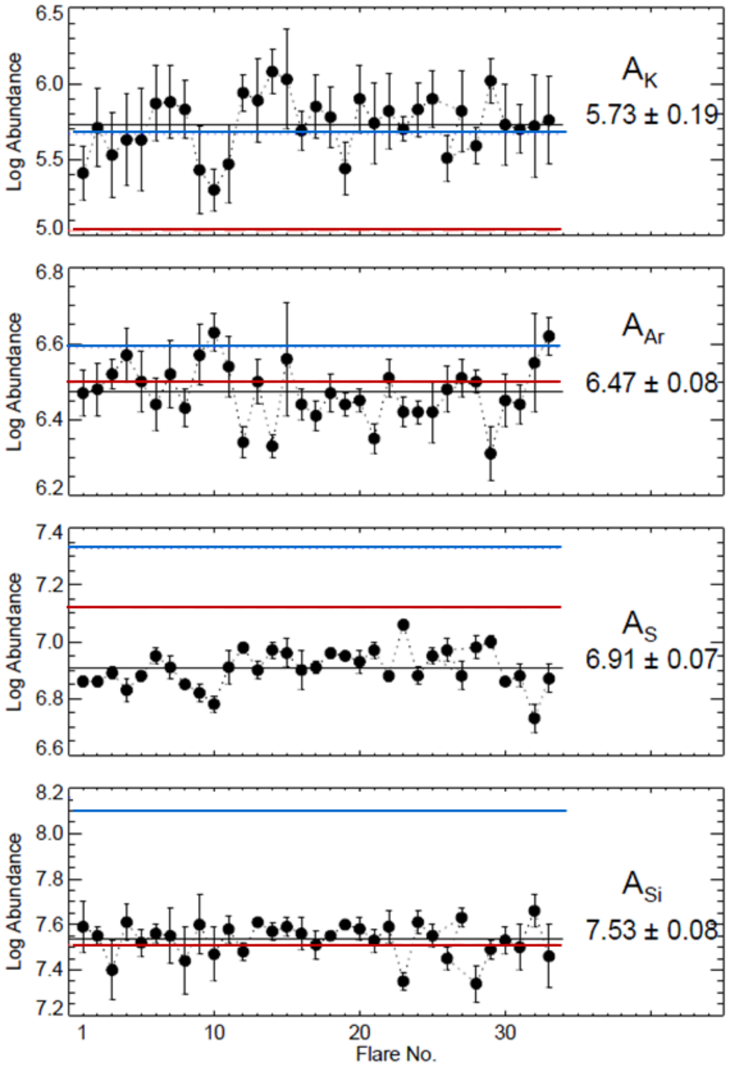


25 Dec. 2002 ~ 18:09 UT C2.9 | 29 Dec. 2002 ~ 02:59 UT B9.9 | 9 Jan. 2003~ 01:39 UT C9.8 | 7 Jan. 2003 ~ 07: 50 UT M1.0

Analysed were 33 flares: located on the disc and limb, short and long duration, different X-ray classes (mainly C & M):

- 1 of B (B9.9)
- 26 of C
- 5 of M
- 1 of X (X1.5, rise & decay only)

The main results published



RESIK solar X-ray flare element abundances on non-isothermal assumption*; B. Sylwester, K.J.H. Phillips, J. Sylwester, A. Kępa, ApJ, 805, 49S, 2015→ 33 flares analysed*

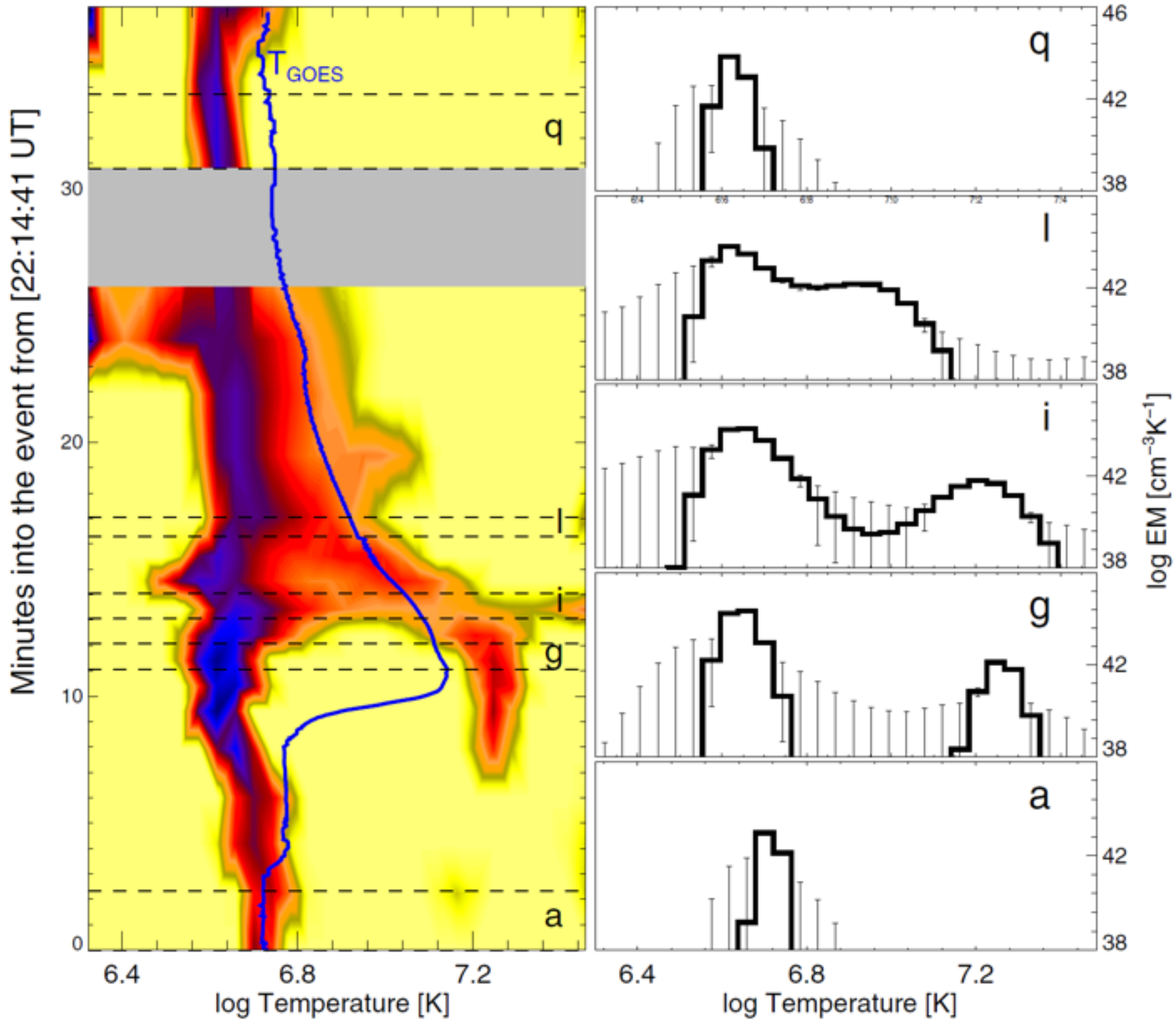
- K (FIP=4.34 eV) average abundance near coronal value (spread over a wide range from 5.3 to 6.1)
- Ar (FIP=15.76 eV) average abundance near photospheric but induvidual values are varying from 6.3 to 6.65
- S (FIP=10.36 eV) mean abundance **always below photospheric** (inverse FIP effect ??)
- Si (FIP=8.15 eV) abundance close to photospheric

Coronal abundances (Feldman et al., 1992)
(CHIANTI database)

Photospheric abundances (Asplund et al., 2009)
except for Ar (from Lodders, 2008)

The next step: DEM determinations with optimised abundances for every flare

SOL2002-11-14T22:26



As soon as
The amount of
hot plasma
is above 0.001
of the cooler
component the
GOES T rises.

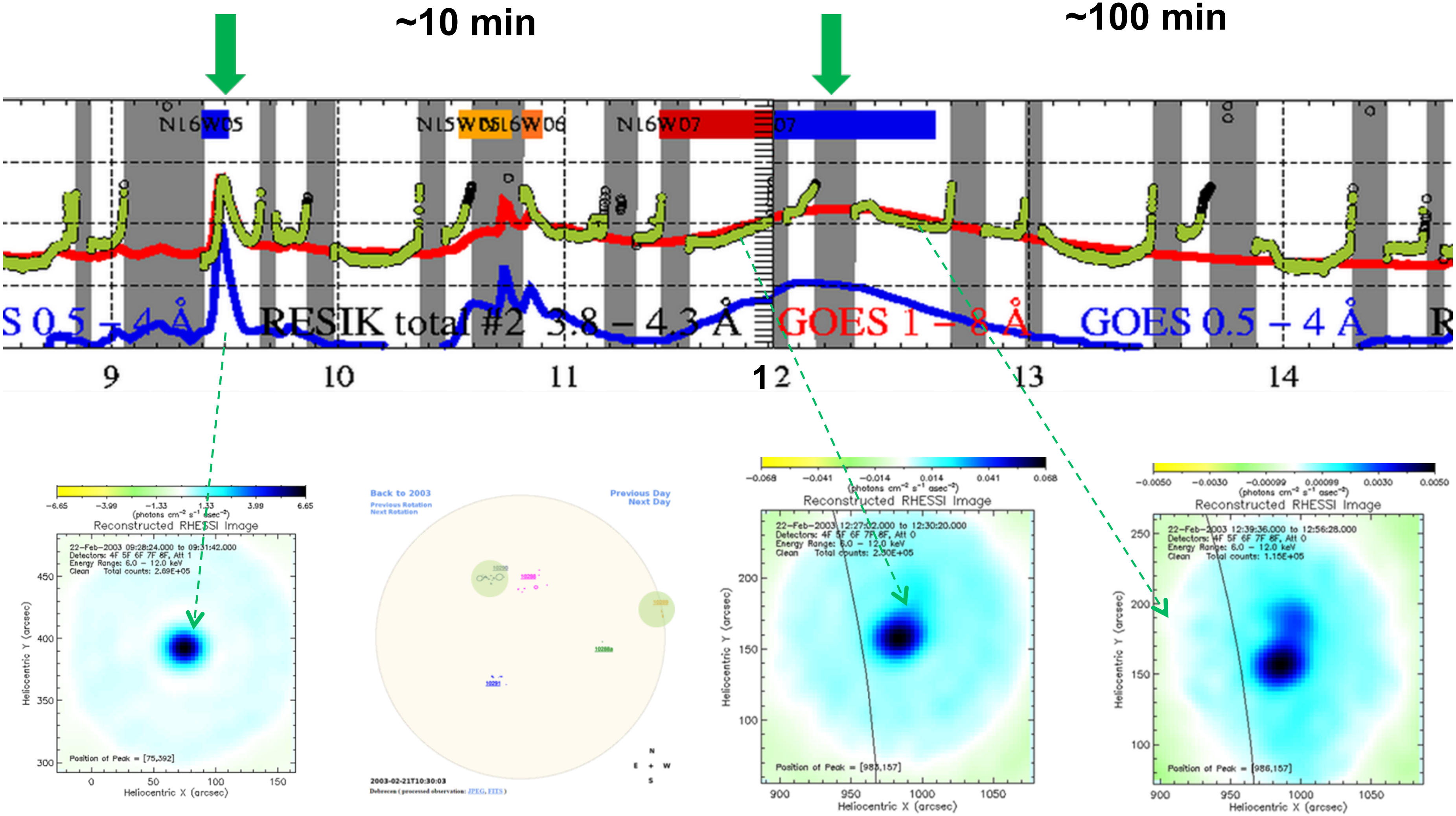
8 orders

RESEARCH IN PROGRESS STUDY DEM FOR BEST OBSERVED EVENTS

example: two 22 February 2003 flares

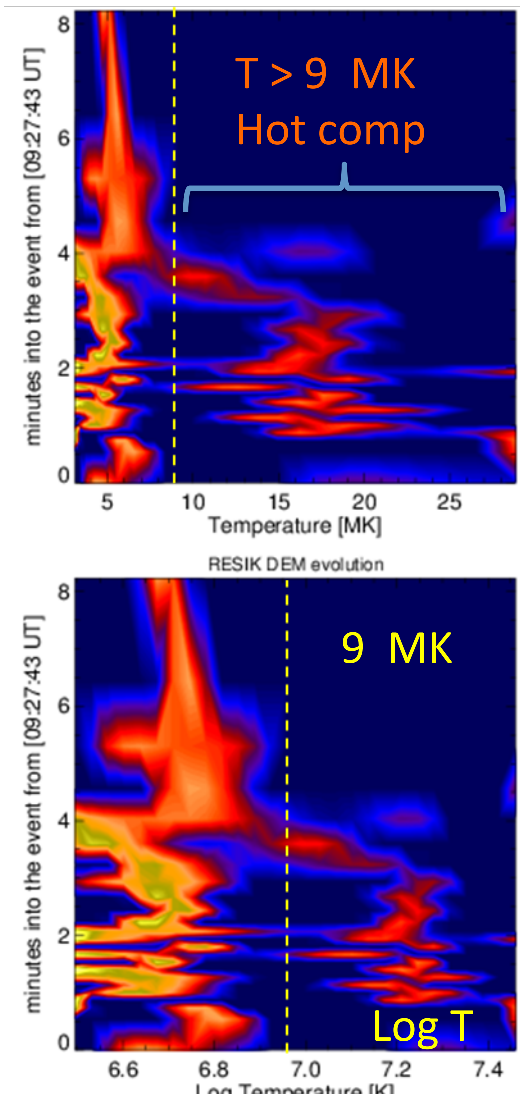
09:29 UT C 5.8 disc event ~10 min

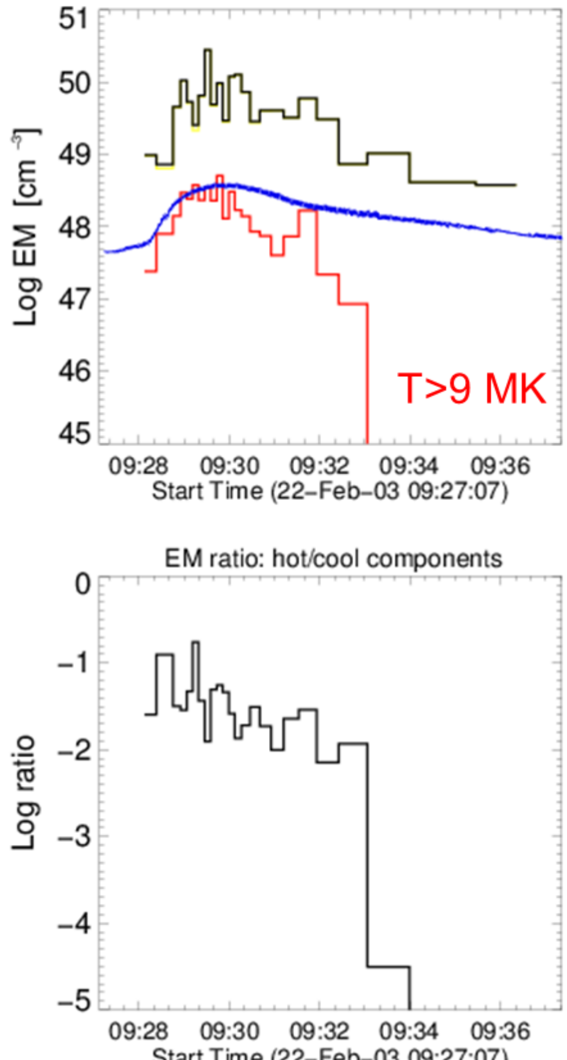
12:20 UT C 1.7 limb event ~100 min

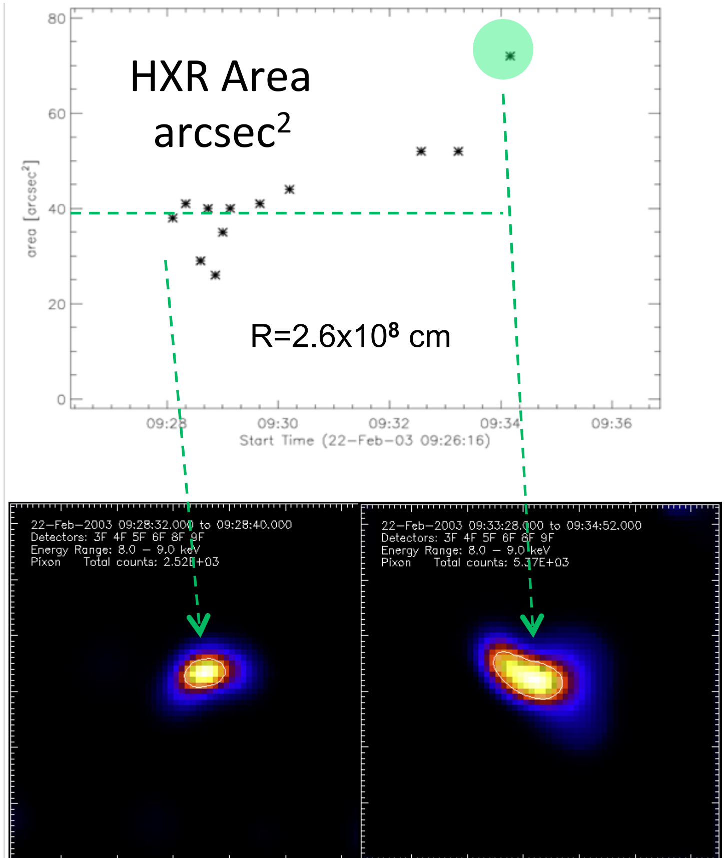


Debrecen map: http://fenyi.sci.klte.hu

The first event:
22 Feb. 2003 ~09:29 UT C5.8 (disc)

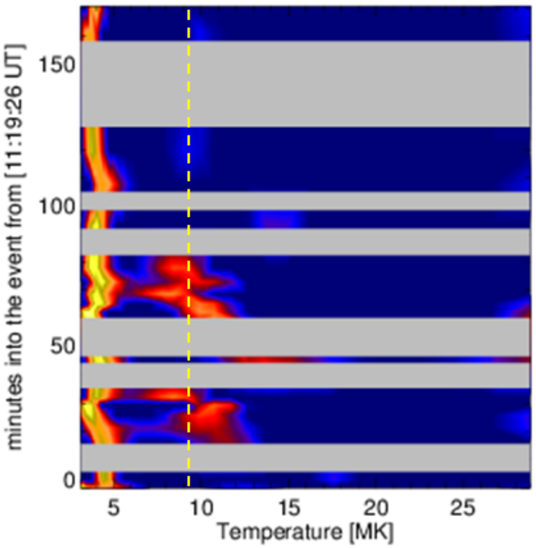


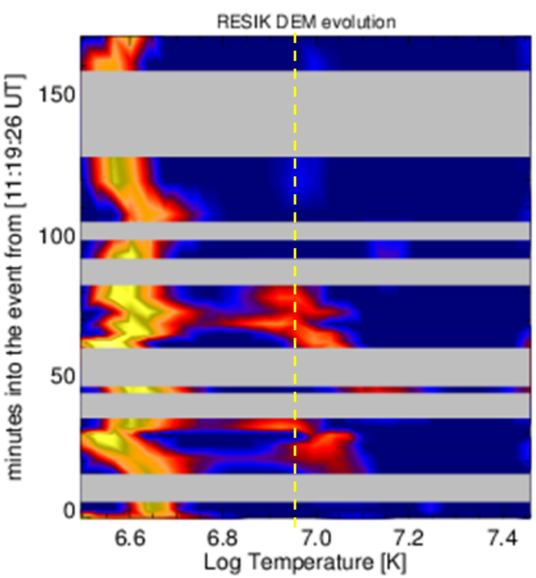


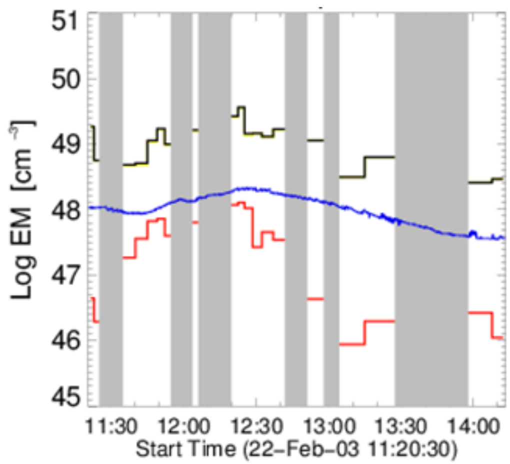


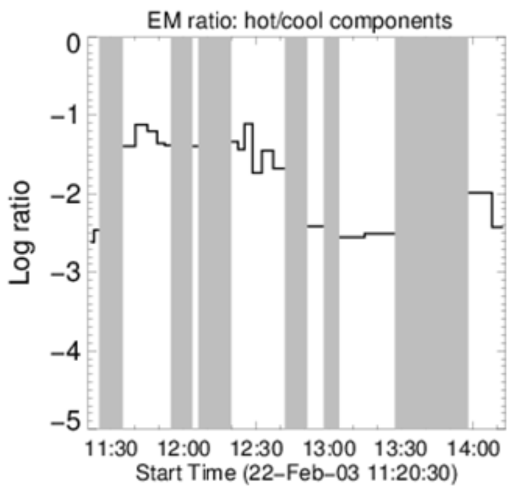
Message: GOES isothermal (T, EM) interpretation is **BIASED**: represents the hot component during rise, later is complicated av.

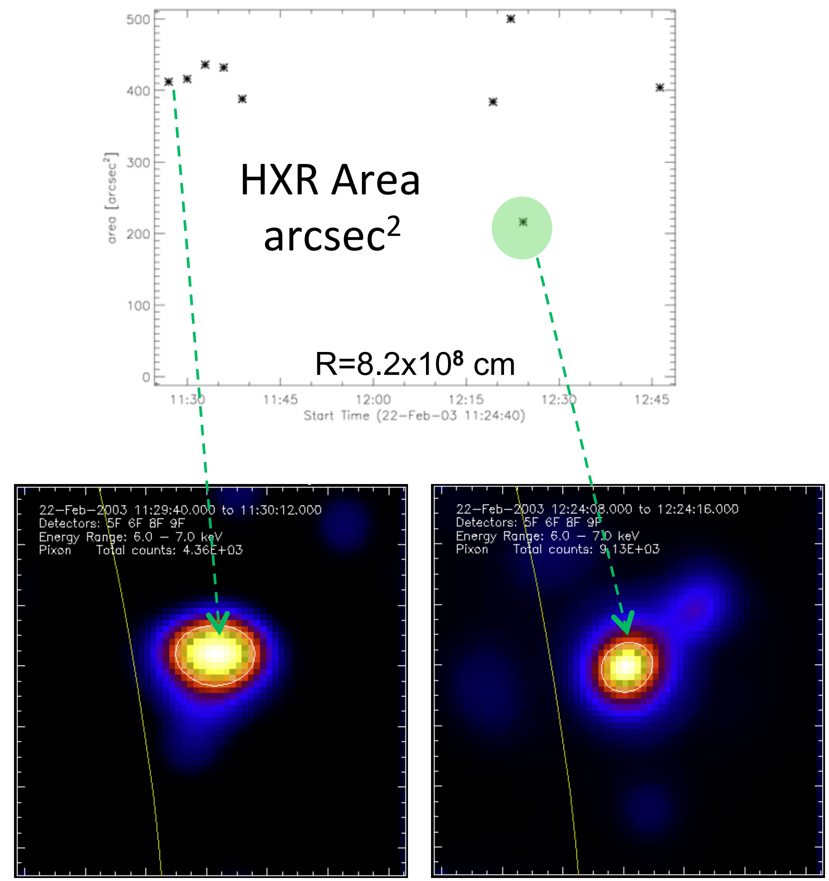
The second, longer flare
22 Feb. 2003 ~12:20 UT   C1.7 (limb)









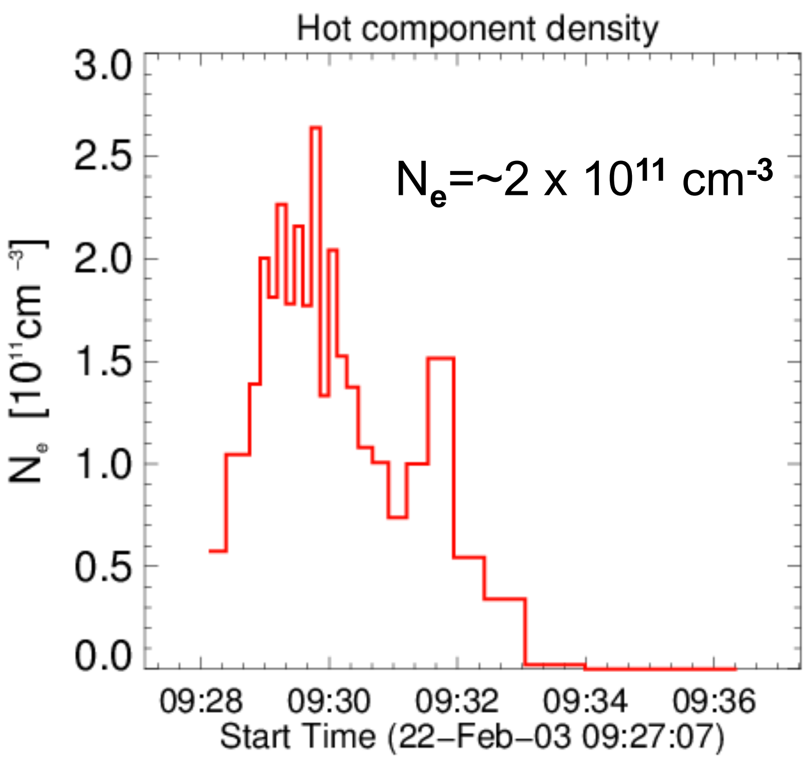


PIXON reconstructed HXT images (~6 keV) provide spatial extend of the hotter component

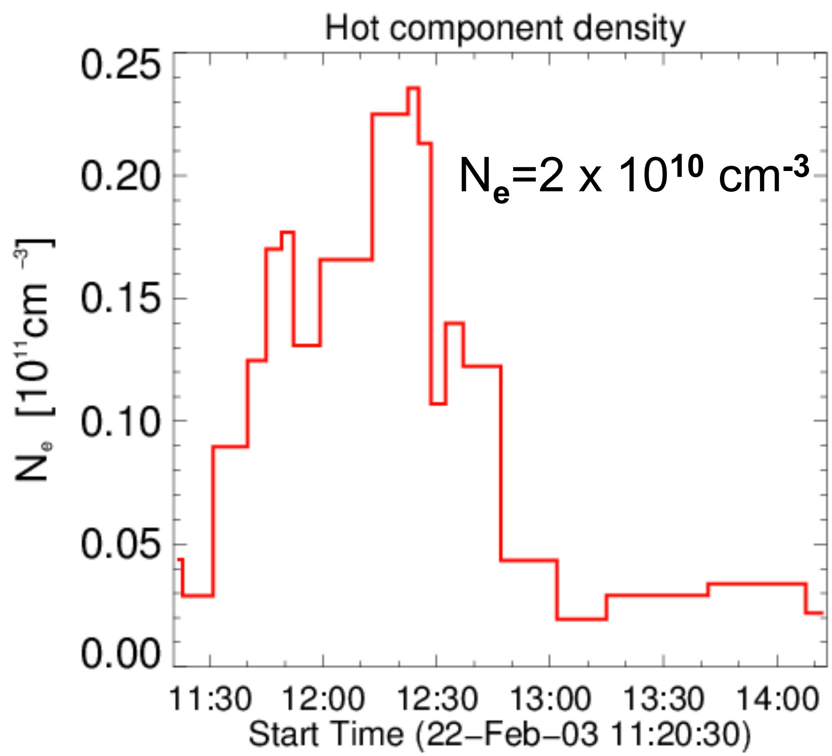
Density changes for these two flares (on 22 Feb. 2003)

$$N_e = (EM/V)^{1/2} \; ; \; V = 4/3\pi R^3$$

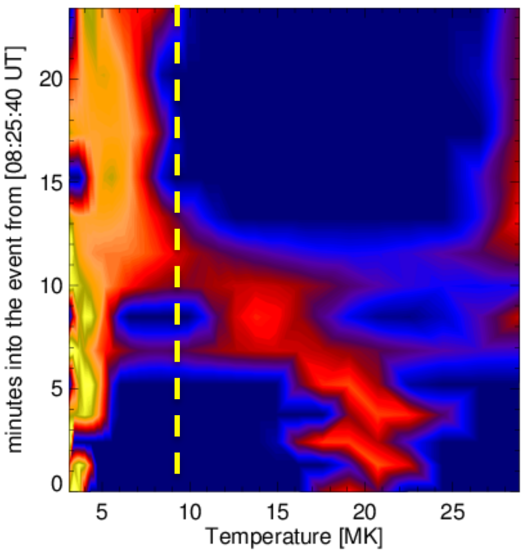
C 5.8 flare (disc, short duration)

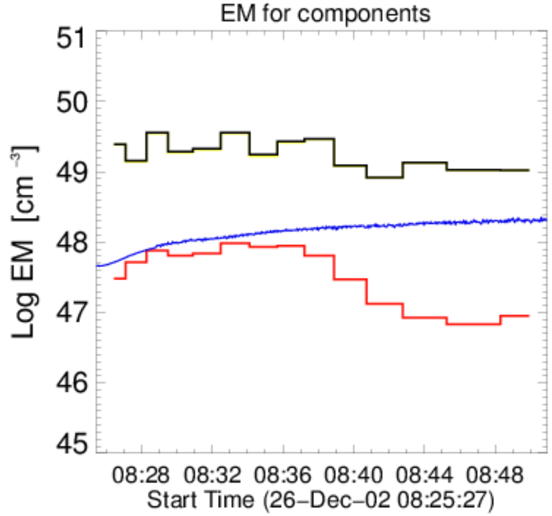


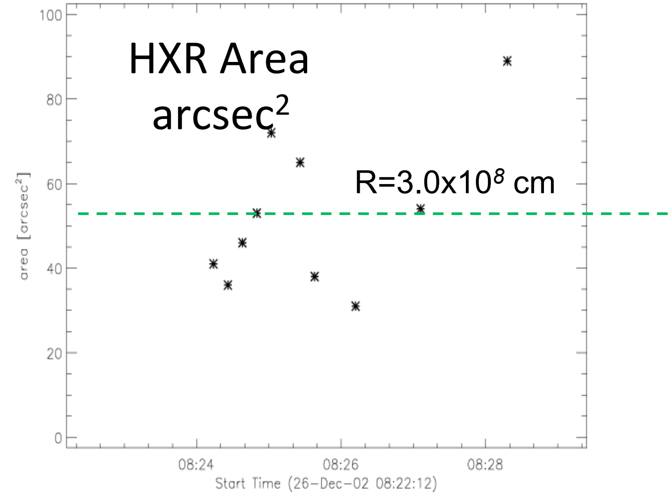
C 1.7 flare (limb, 10 x longer)

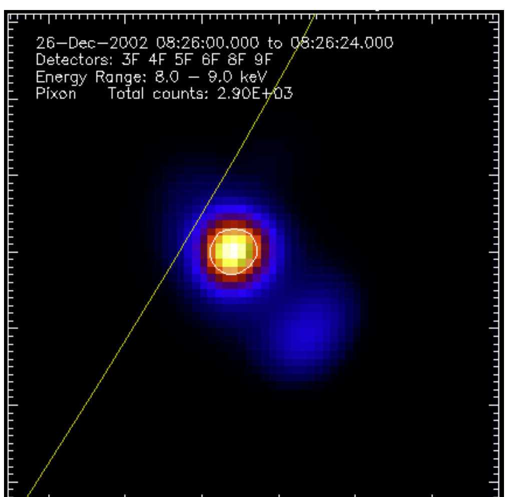


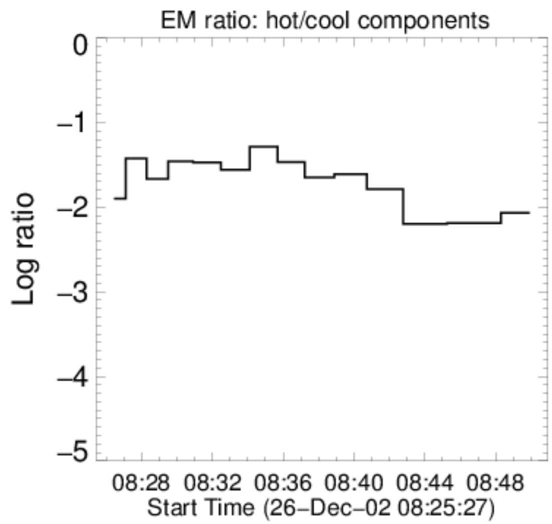
Another flare from the good set
26 Dec. 2002 ~08:35 UT C1.9 (limb)

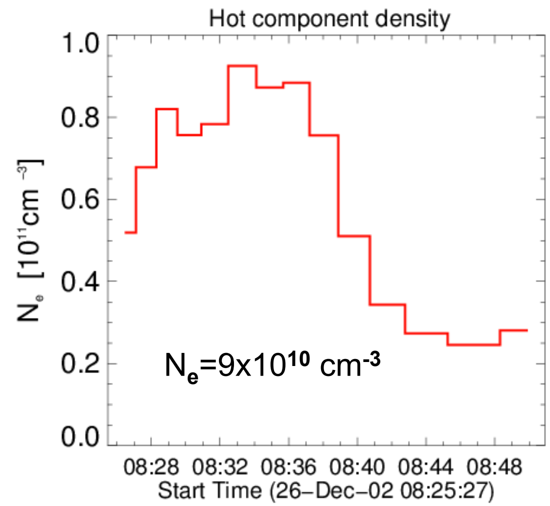




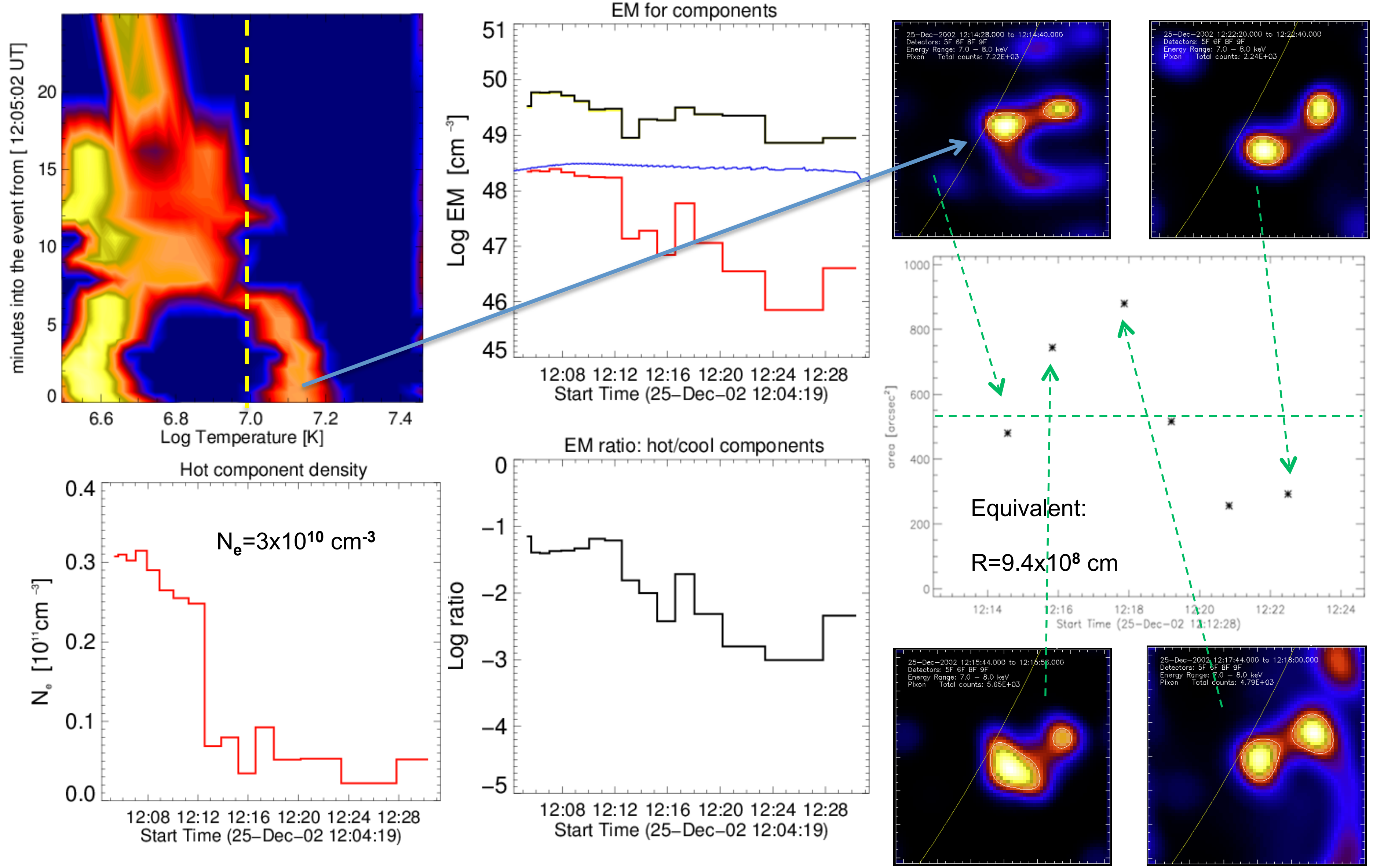




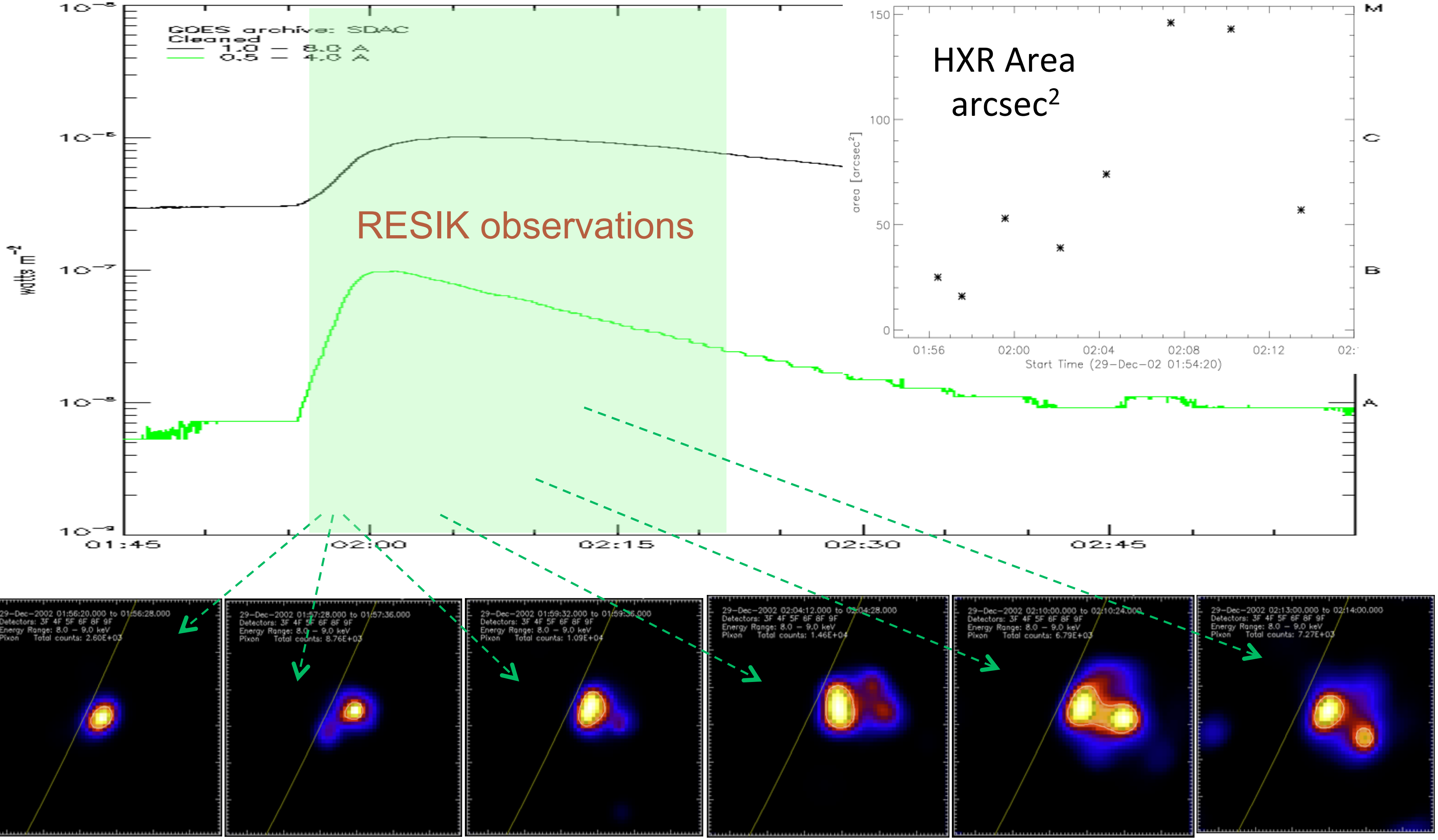




Still another event
25 Dec. 2002 ~12:07 UT C3.5 (limb, double source)

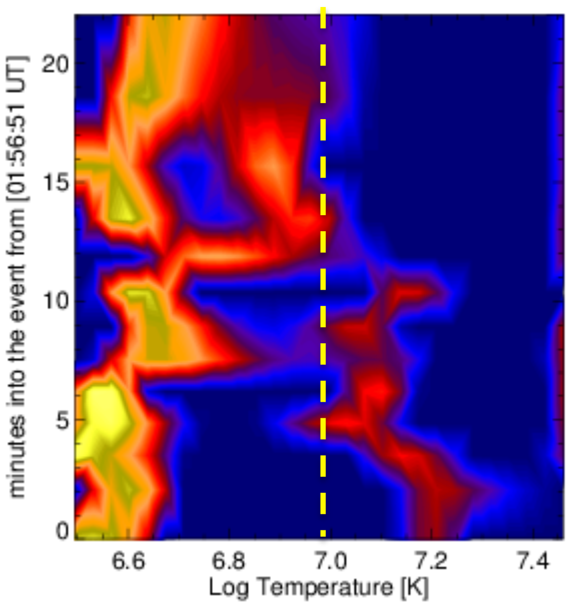


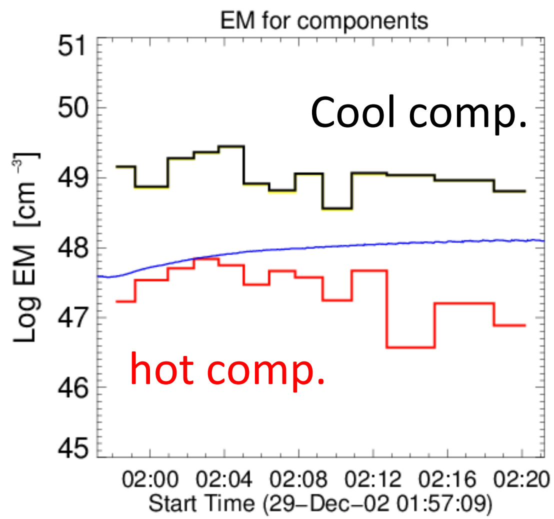
One of the weakest Long duration flares observed 29 Dec. 2002 ~02:05 UT B9.9: our best flare



PIXON reconstructed *RHESSI* images→ changing volume of 8-9 keV emitting plasma

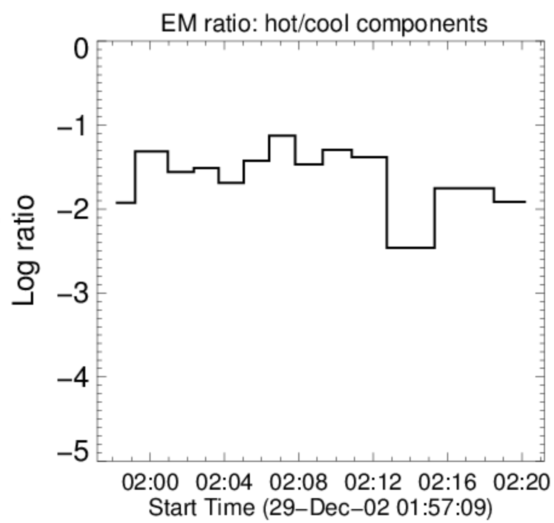
29 Dec. 2002 ~02:05 UT B9.9 (limb)

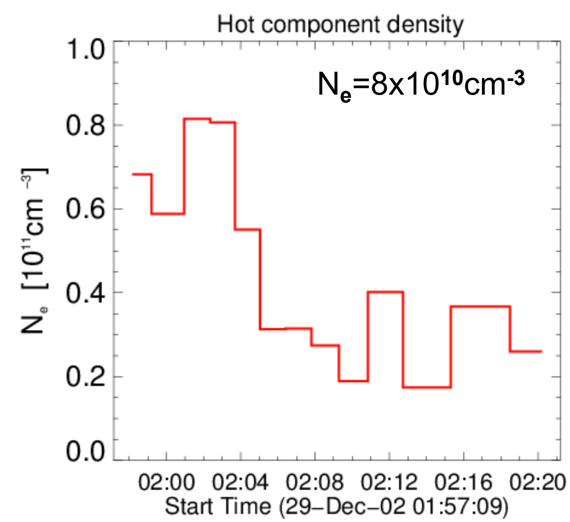




By combining time dependent EM & volume of the emitting region a pattern of density variations is revealed

Nearly constant ratio of hot and cooler plasma (as we defined it)





Concluding remarks

- RESIK spectra allow us to determine abundances of main elements contributing to the spectra (K, Ar, S, Si) and also the time evolution of the differential emission measure distributions (DEMs).
- The DEM shapes indicate 2 components – a cooler component (T = 3 – 9MK) and a hotter component (T>9MK). The amount of plasma in the cooler component is approx. constant with time but the hotter component (which accounts for a tiny fraction of the total DEM) is variable.
- PIXON-reconstructed *RHESSI* maps when available enable estimates of the high-T emitting volumes to be made from which lower limits to electron densities can be set.
- For moderate-class flares, the lower limits of hot plasma averaged densities are between 2×10^{10} cm^{-3} and 2×10^{11} cm^{-3}.
- We are looking for scaling laws which will allow to estimate the hot plasma density from the total energy and duration of the flare.

25 Dec. 2002 ~06:02 UT C4.0 (limb)