RESIK SOLAR X-RAY FLARE ELEMENT ABUNDANCES ON A NON-ISOTHERMAL ASSUMPTION

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Are there abundance differences "FIP effect" between/during flares? Sylwester, 1984 Nature SMM data

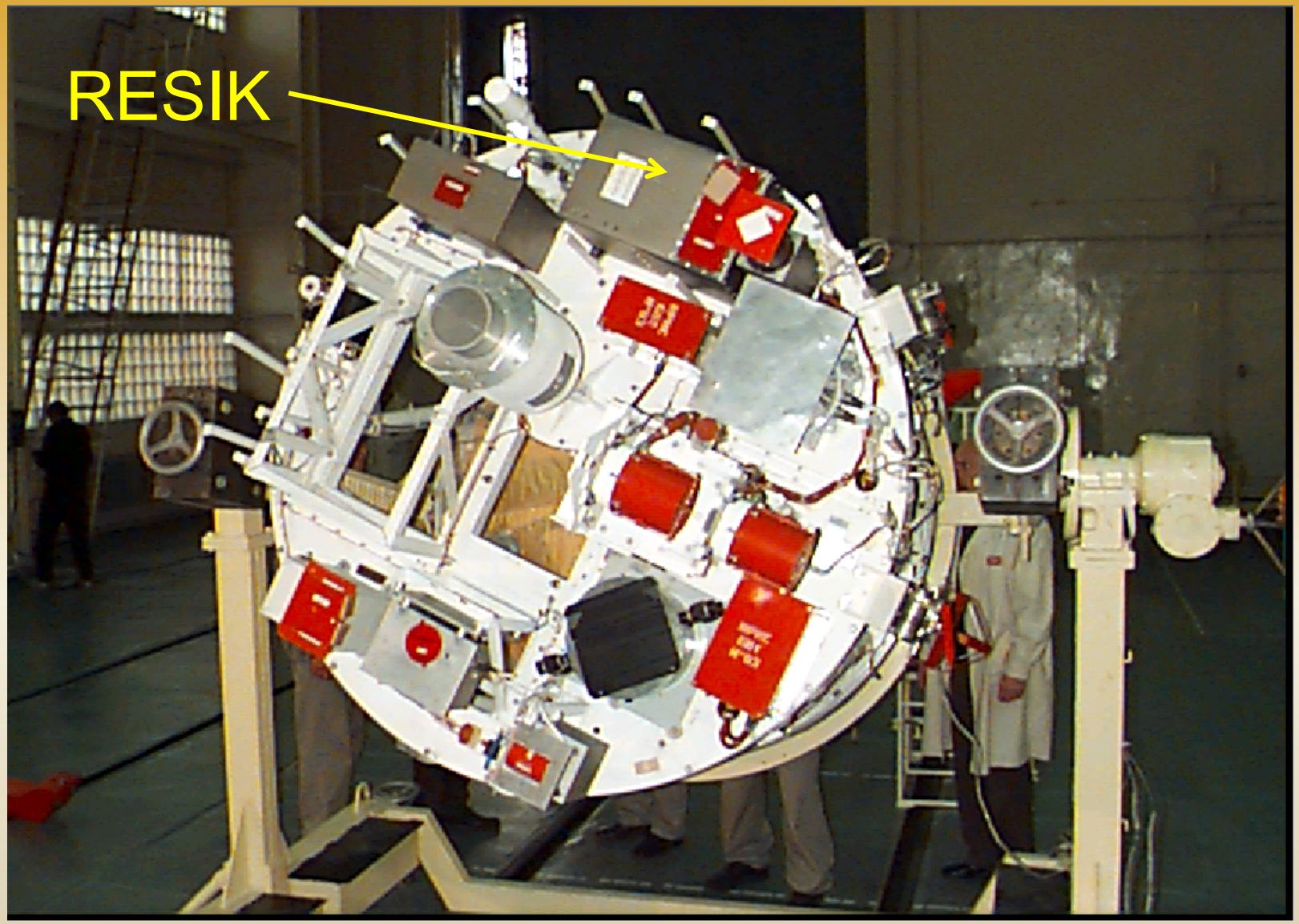
RESIK was Polish-led uncollimated spectrometer placed aboard the CORONAS-F satellite. It was the follow-on of the *Yohkoh* Bent Crystal Spectrometer and used its spare detectors. RESIK observed in the spectral range **3.3–6.1 Å**

with the principal X-ray emission lines of elements with various values of the first ionization potential FIP: **K** (FIP=4.34 eV), **Si** (FIP=8.15 eV),

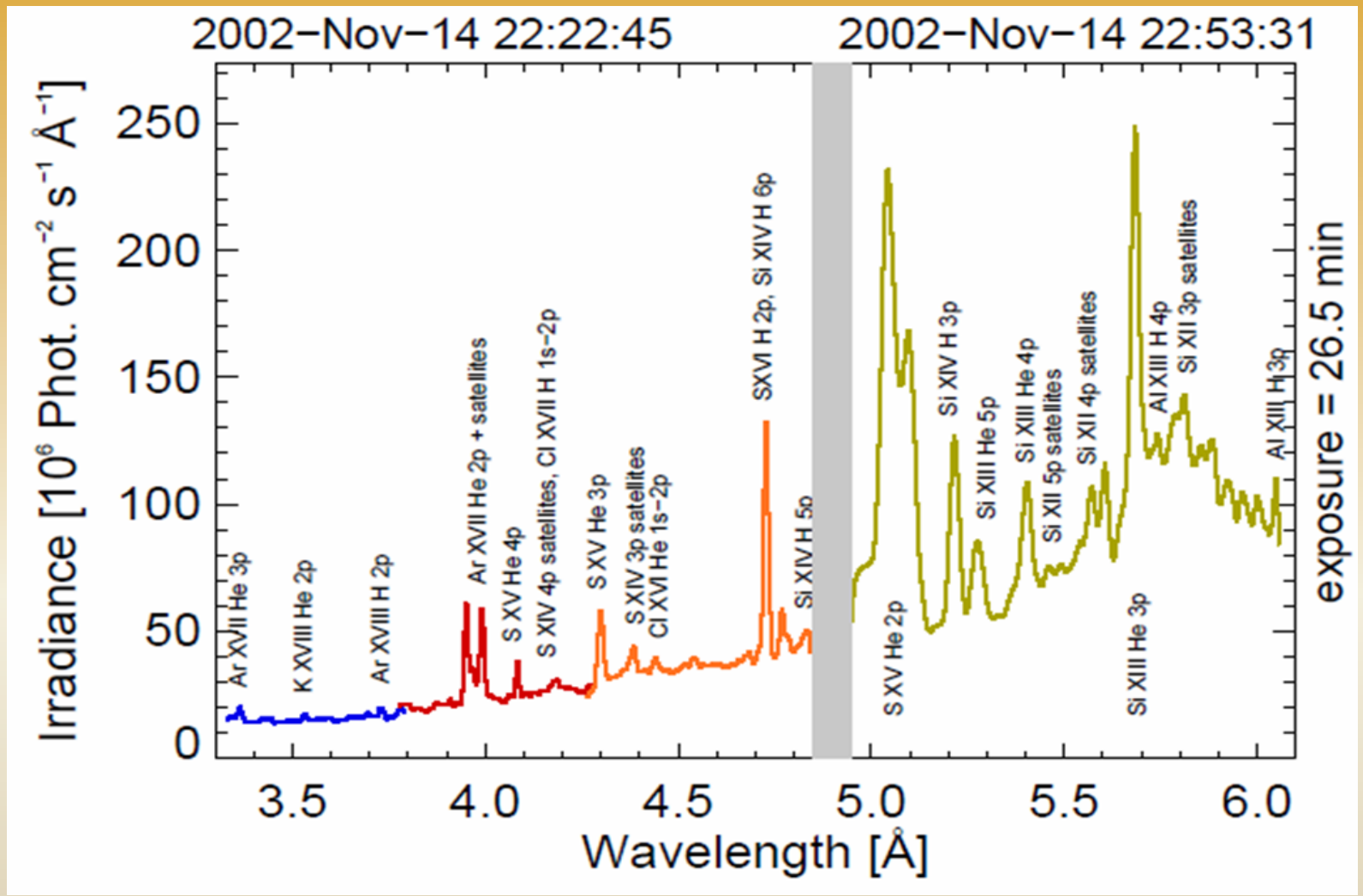
S (FIP=10.36 eV), **Cl** (FIP=12.97 eV),

Ar (FIP=15.76 eV).

RESIK was a separate box on the *CORONAS-F* payload, the instrument computer was placed in the sealed compartment

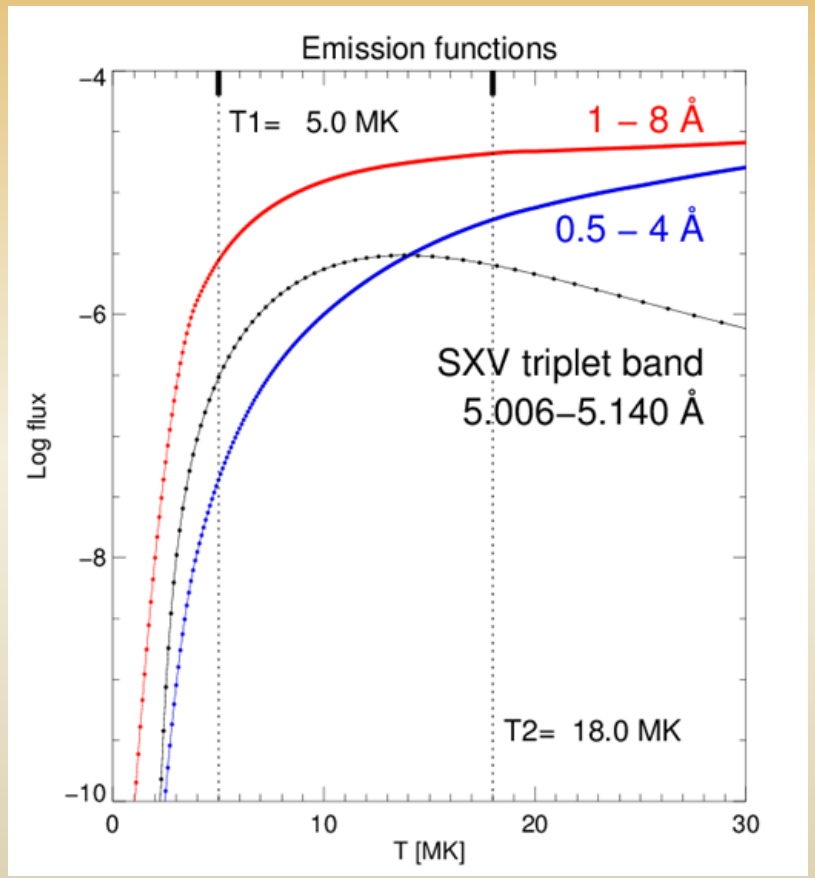


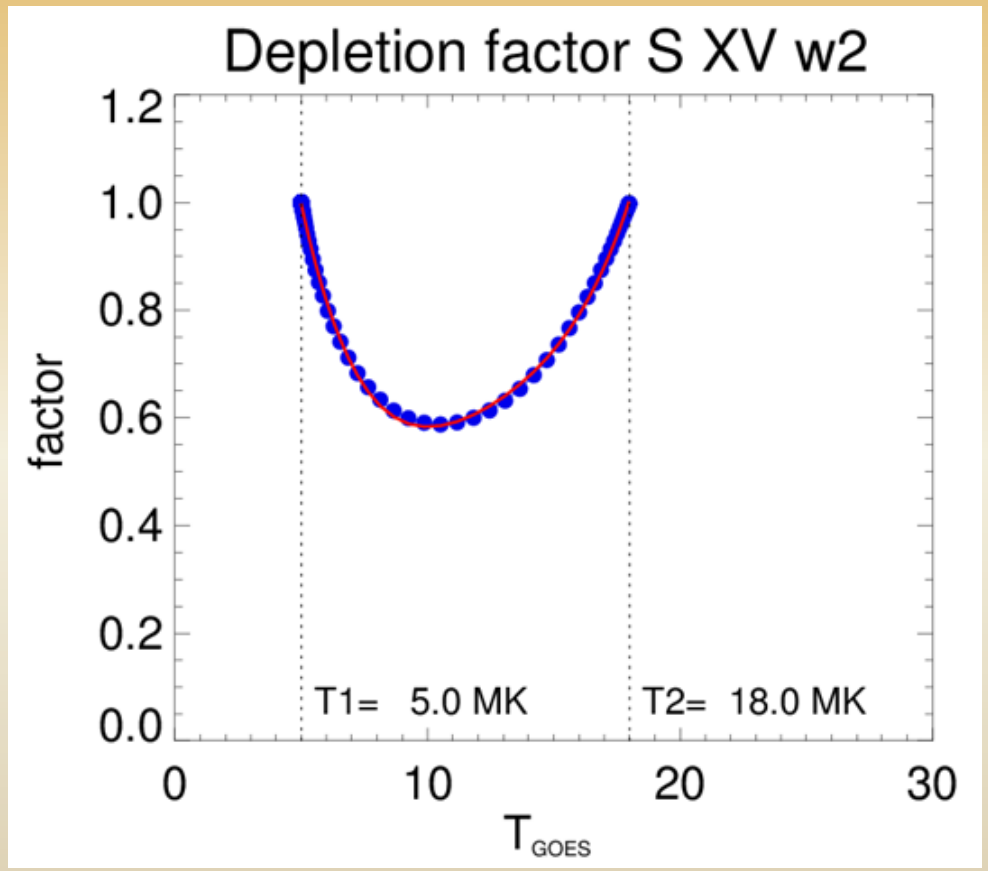
Example spectrum for M1.0 flare



The method:
determin elemental abundances in the multithermal approach

Study elemental abundances in the **multithermal approach.**
Why multithermal? → presence of „depletion Factor”





The Aim: Study elemental abundances in the multithermal approach

We introduced an innovative method **AbuOpt** (*Sylwester et al., ApJ 787, 2014*) Offering a possibility for determination of **flare abundances** consistent with all RESIK observed spectral line and continuum intensities.

Abundance determinations obtained for a 33 flares observed are presented and compared with commonly used coronal and photospheric values.

AbuOpt introduction:

(fluxes integrated over whole flare duration)

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

for i=1,2…18

$$DEM \equiv \varphi(T) \equiv N_e{}^2 \frac{\mathrm{d}V}{\mathrm{d}T}$$

A**_i* - an abundance of ***i –

The set of 18 such equations are being so

changing value of ***A**_i* – we assume **21 valu**

We solve the set for the DEM using itera

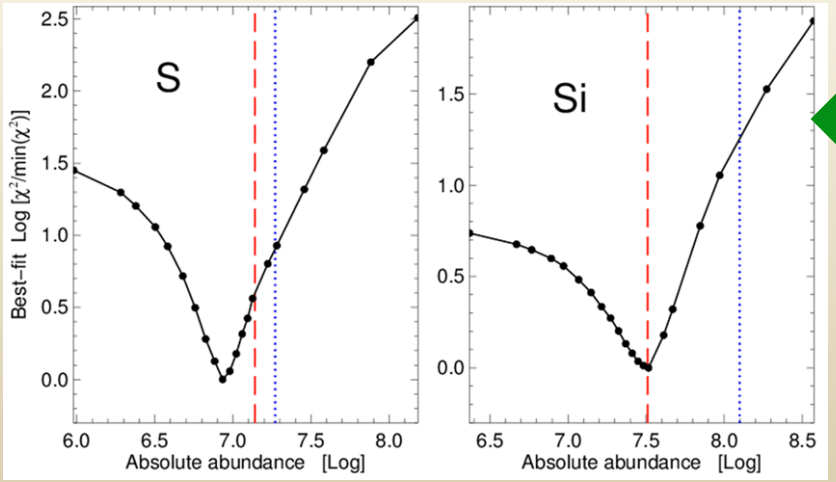
abundance of

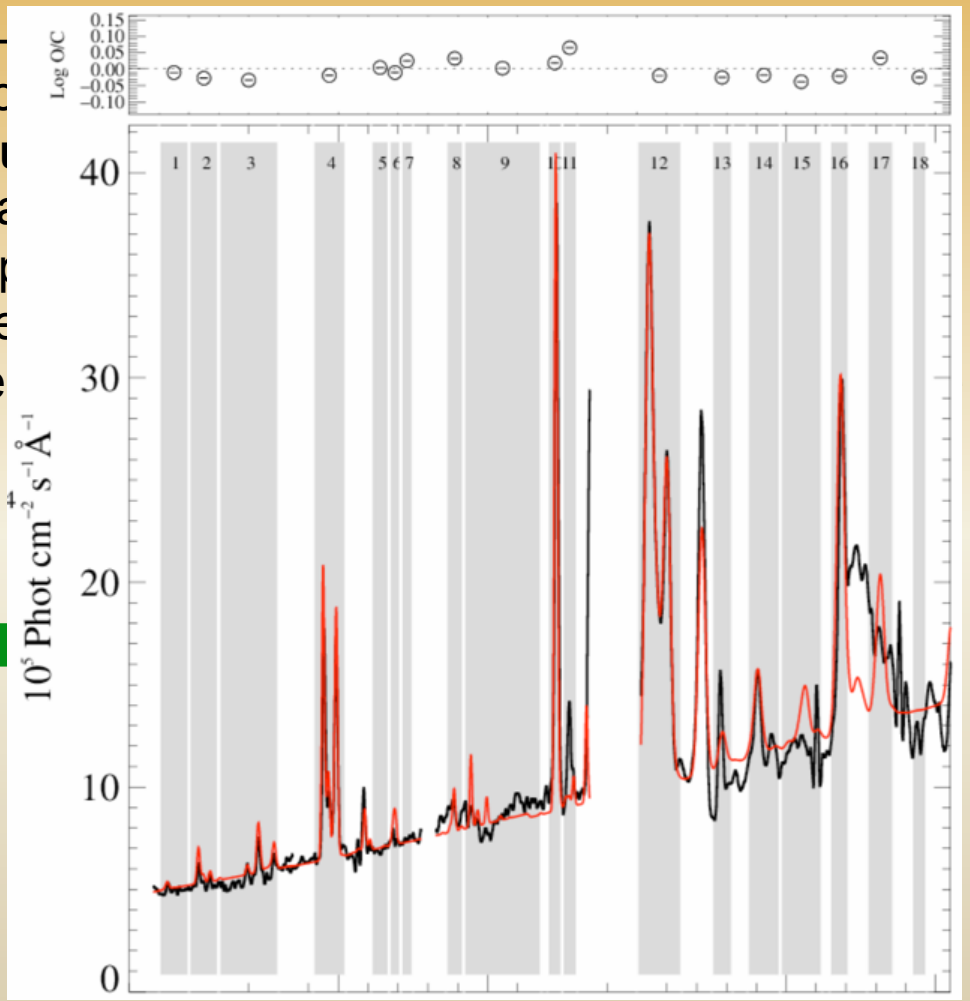
The abundances of “other” elements are

For each of 21 abundance exercises, afte

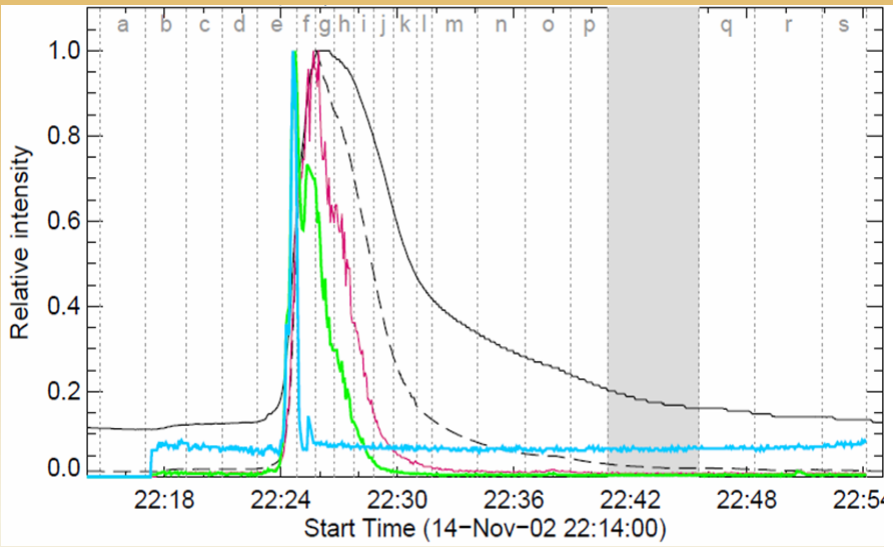
χ^2 (for the fit). The relation of **χ^2 on *A**_i*** is

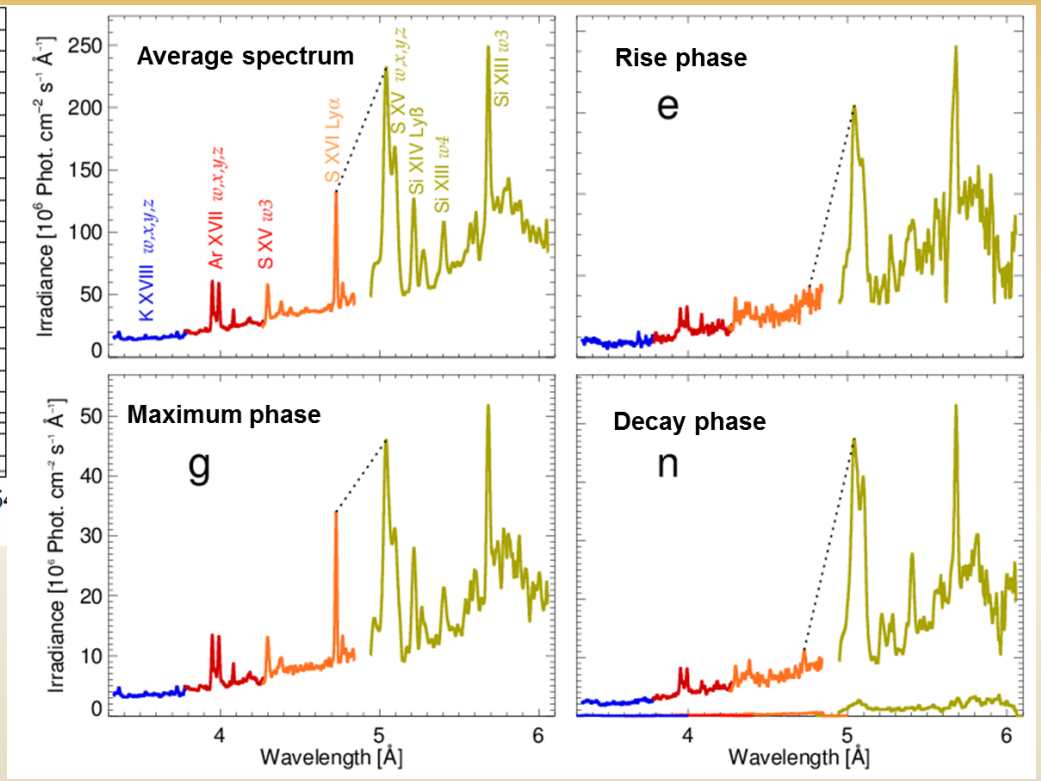
corresponds to the minimum χ^2 value is





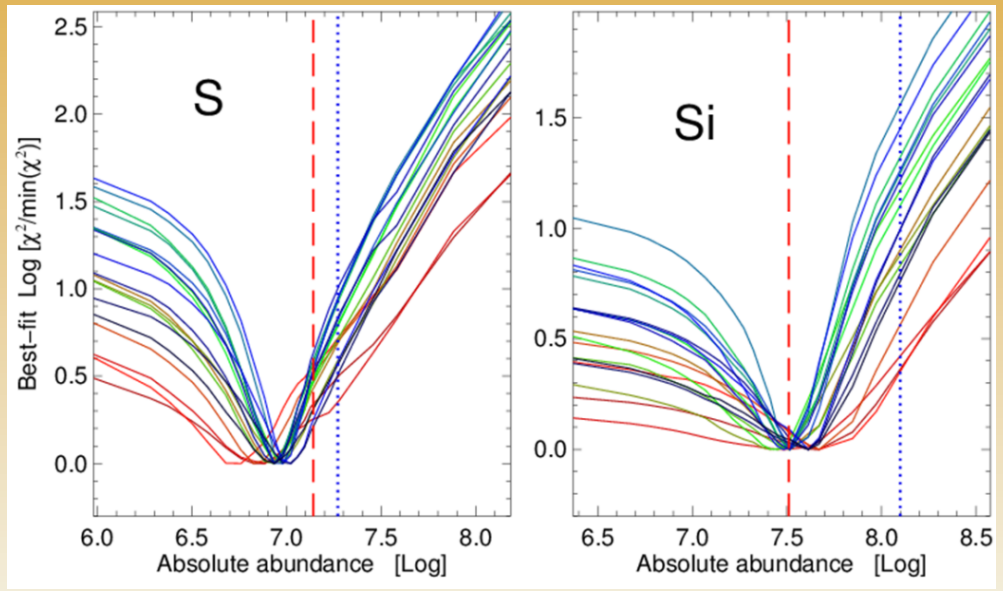
M1 flare on 14 Nov. 2002 at 22:26 UT

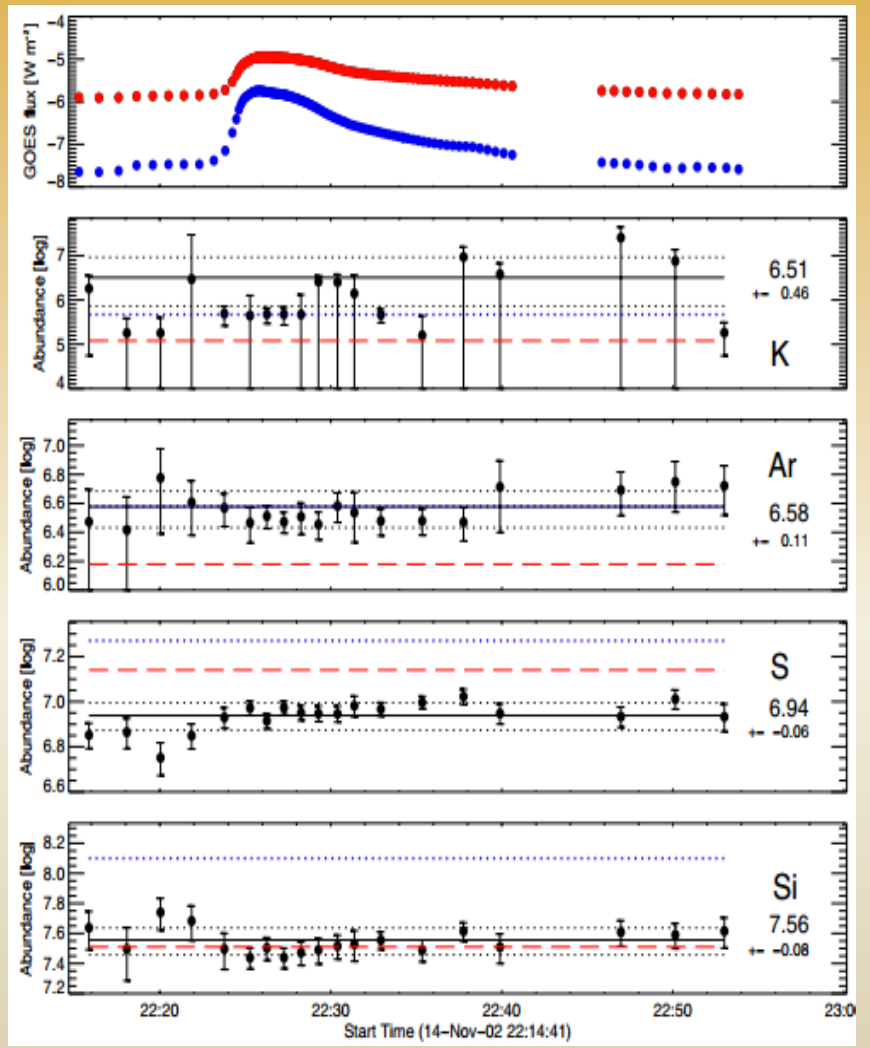




GOES → black
RHESSI → pink (6 - 12 keV)
green (12 - 25 keV)
blue (25 - 50 keV)

14 Nov. 2002; for 19 time intervals

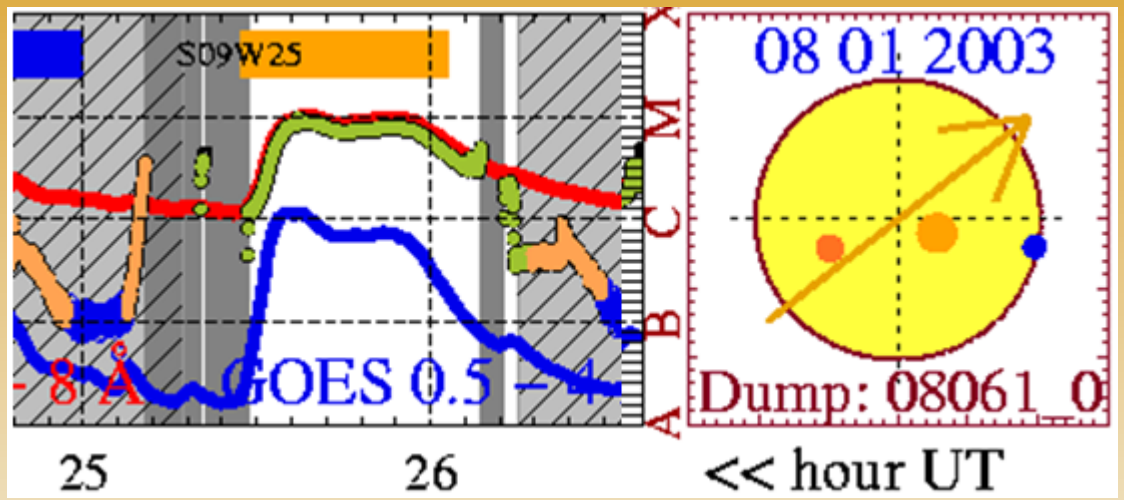


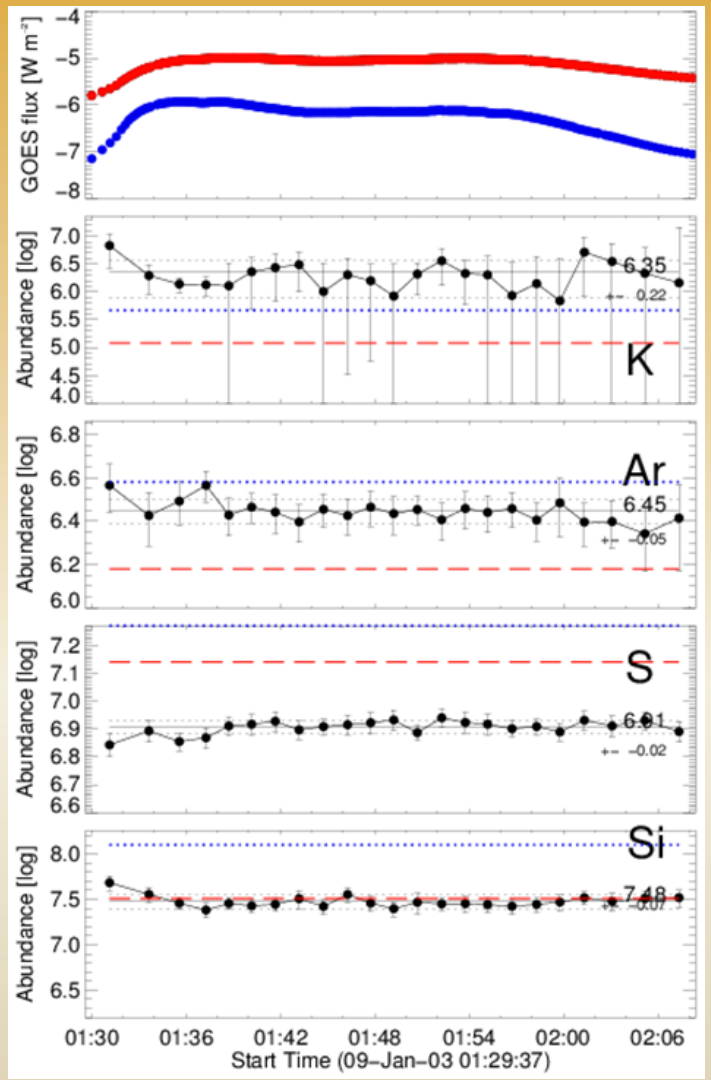


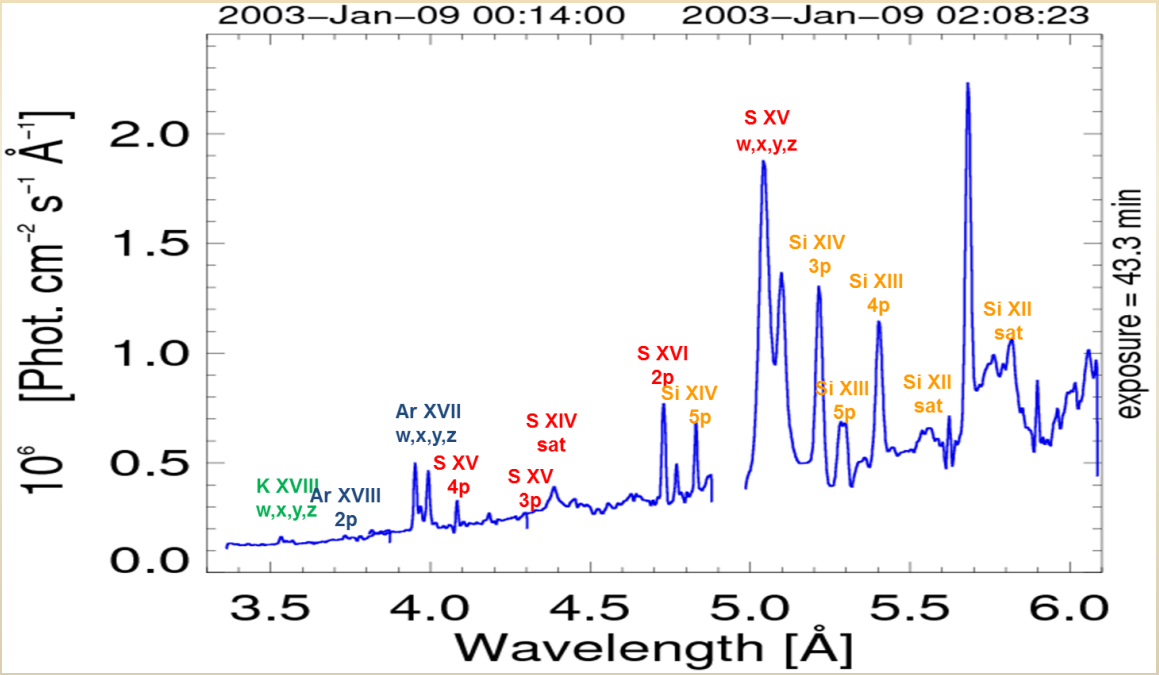
Dashed red line denotes the photospheric and dotted blue the coronal abundances.

Error bars of abundances correspond to values for normalized min(χ^2)+1 (Bevington). **Solid black line** - time averaged values with rms error bars (dotted).

9 Jan 2003 at 01:39 UT; C9.8

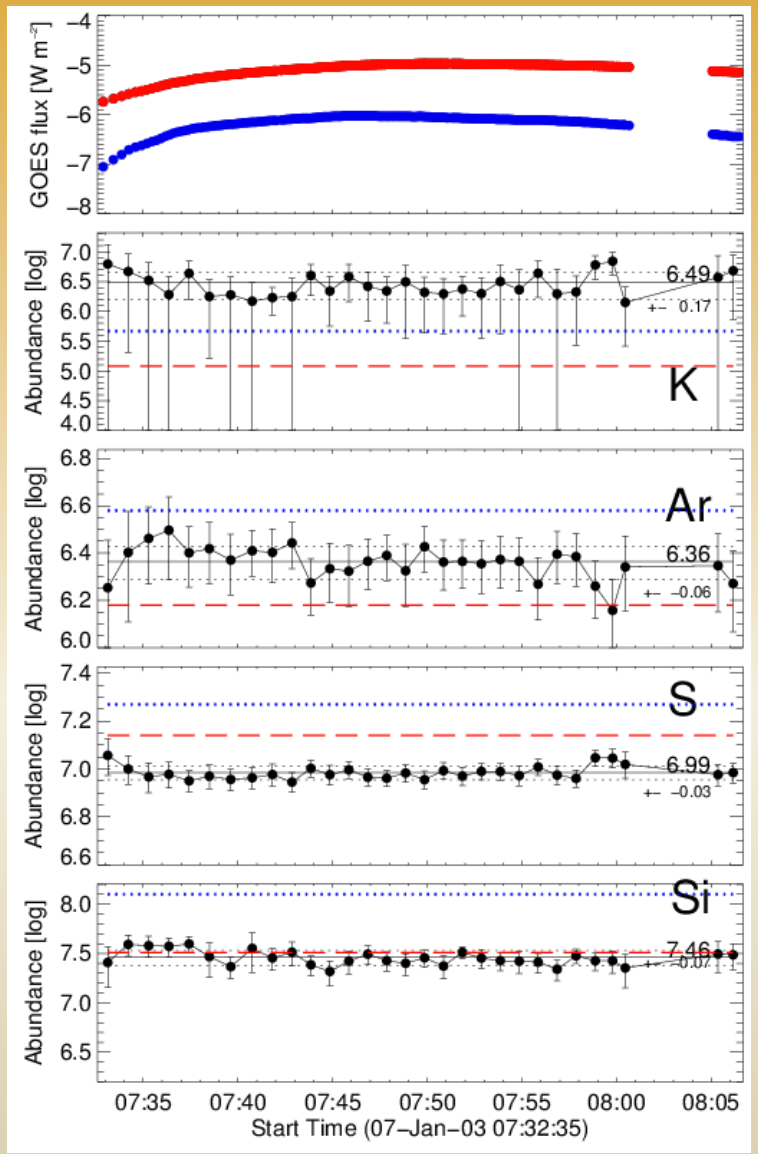


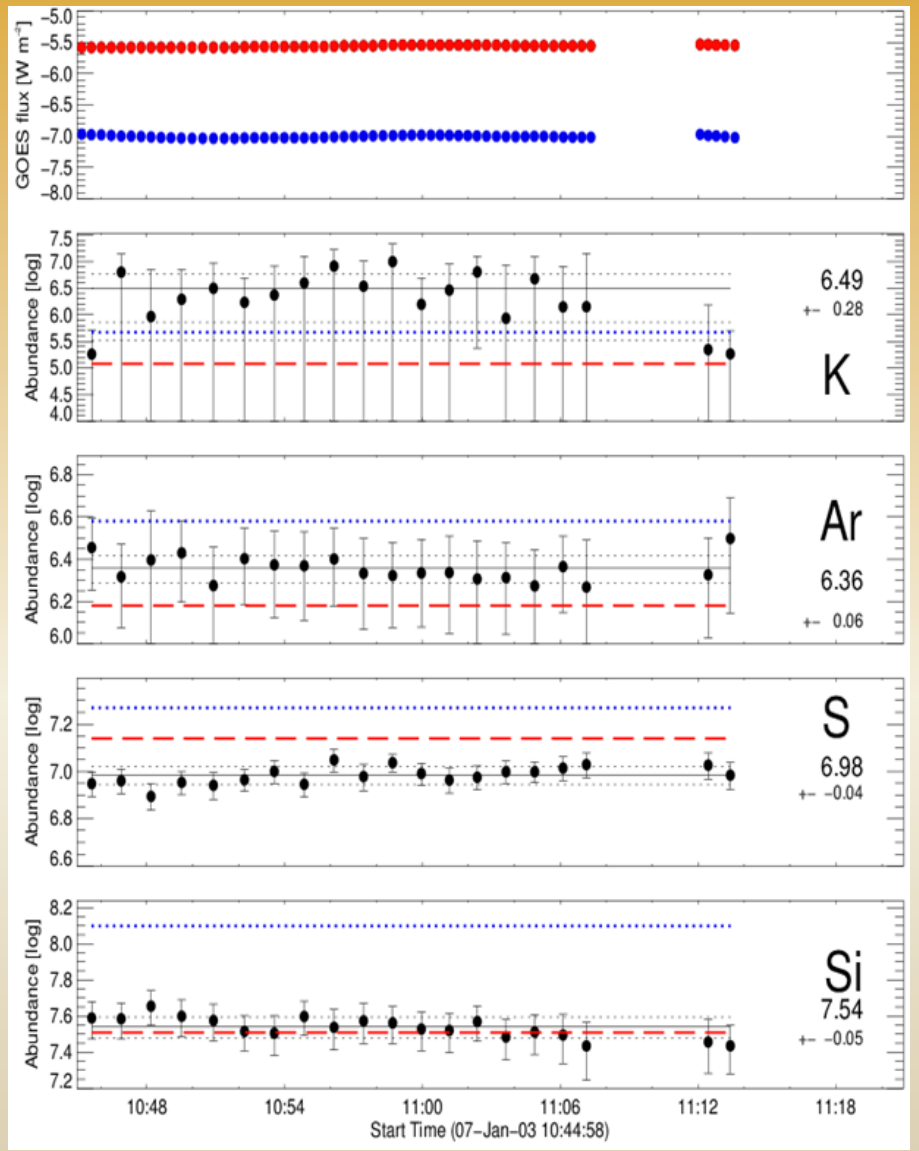




Evolution during flare

7 Jan. 2003~07:50 UT M1.0 ~11:12 UT C2.9



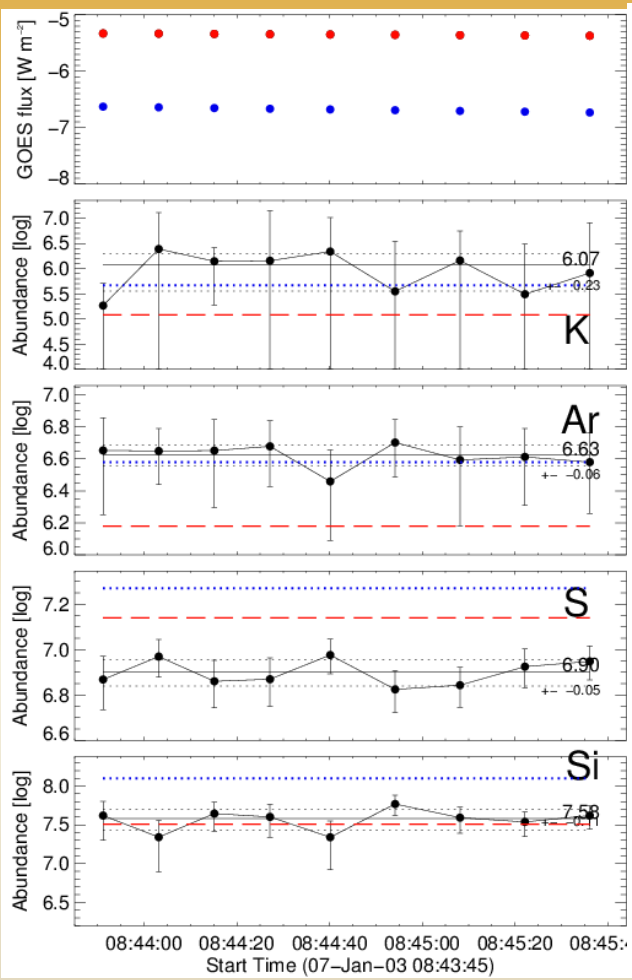


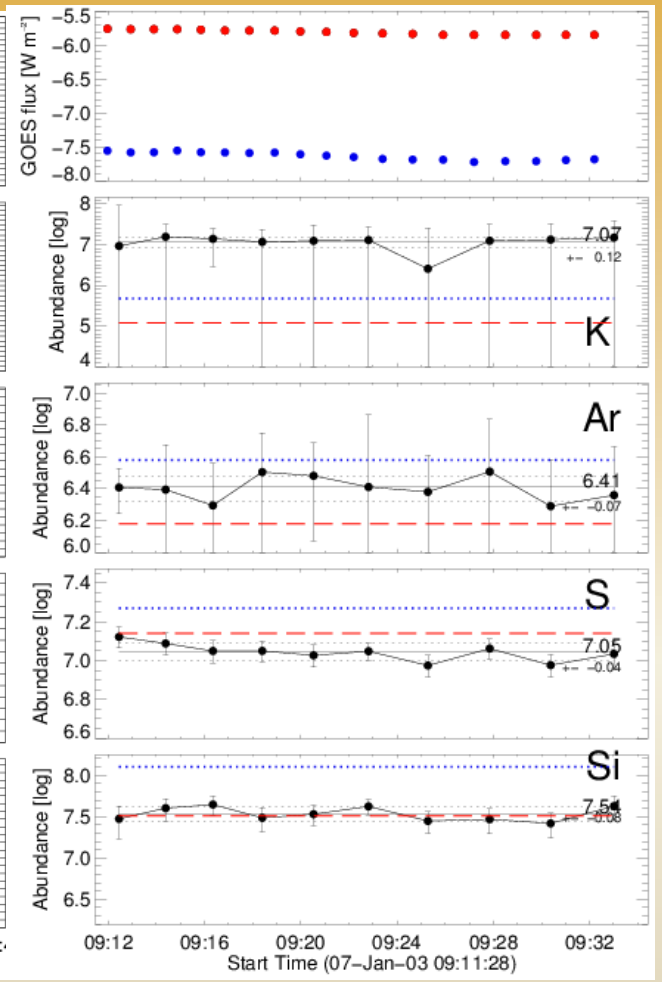
Evolution during flare

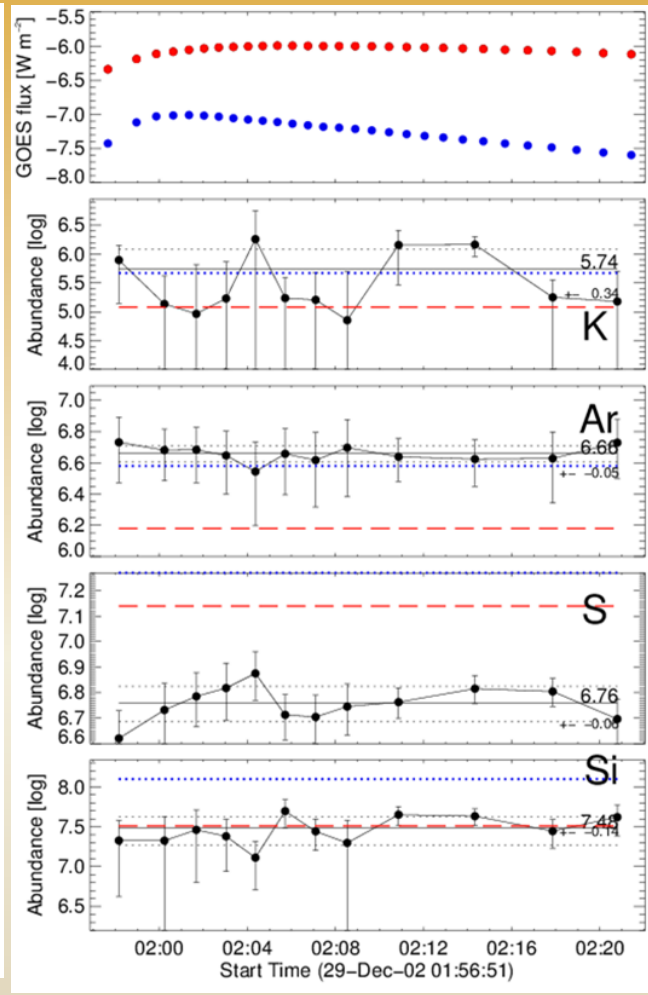
7 Jan. 2003 ~09:15 UT C1.7

7 Jan. 2003 ~08:33 UT C7.7

29 Dec. 2002 : ~02:05 UT B9.9





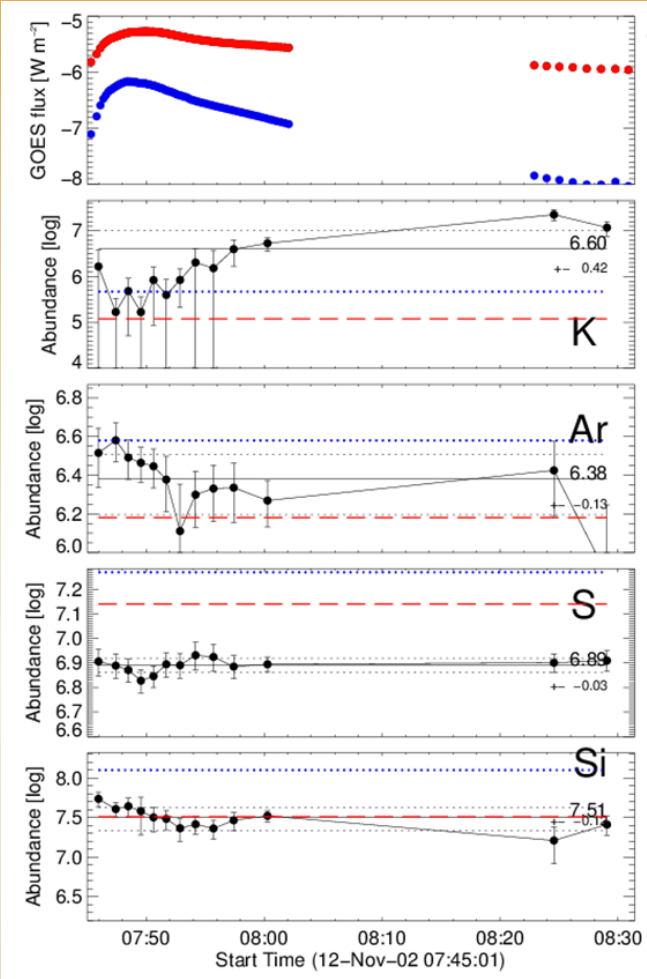


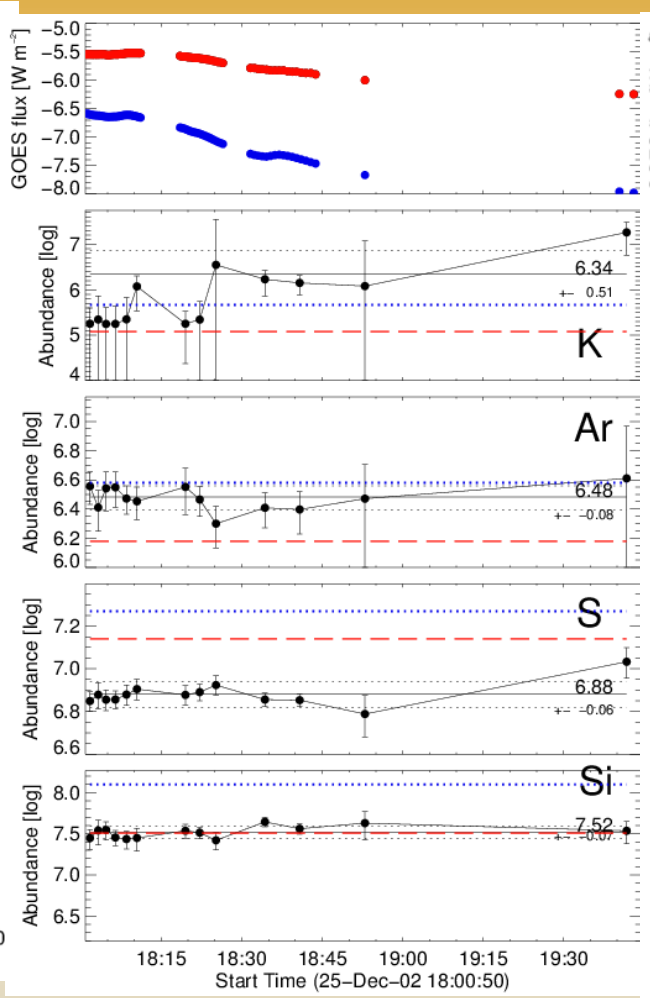
Evolution during flare

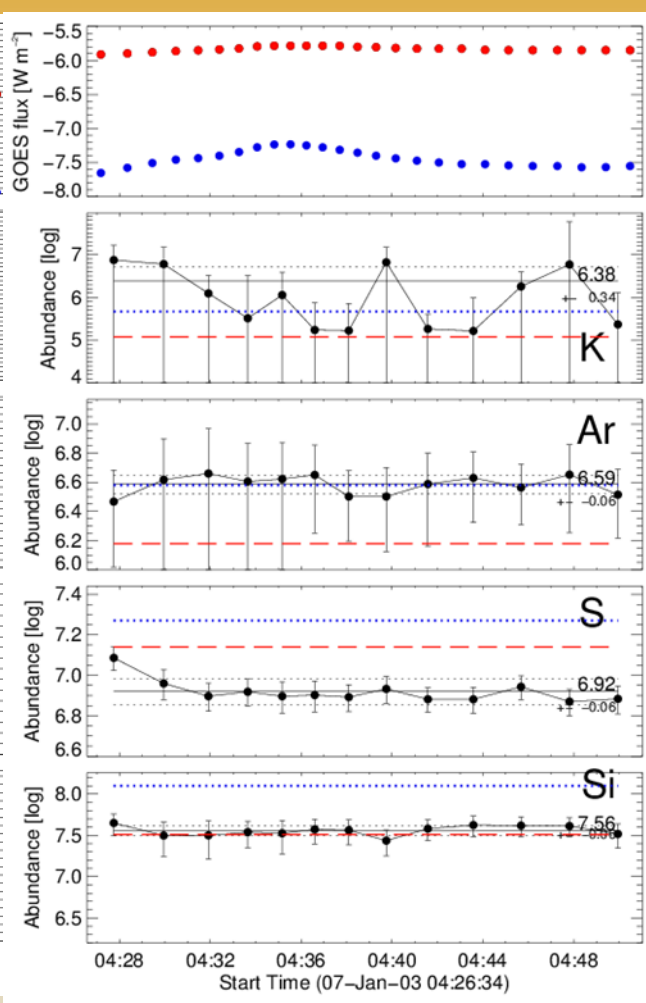
12 Nov. 2002 ~07:49 UT C5.3

25 Dec. 2002~18:09 UT C2.9

7 Jan. 2003 ~04:35 UT C1.6

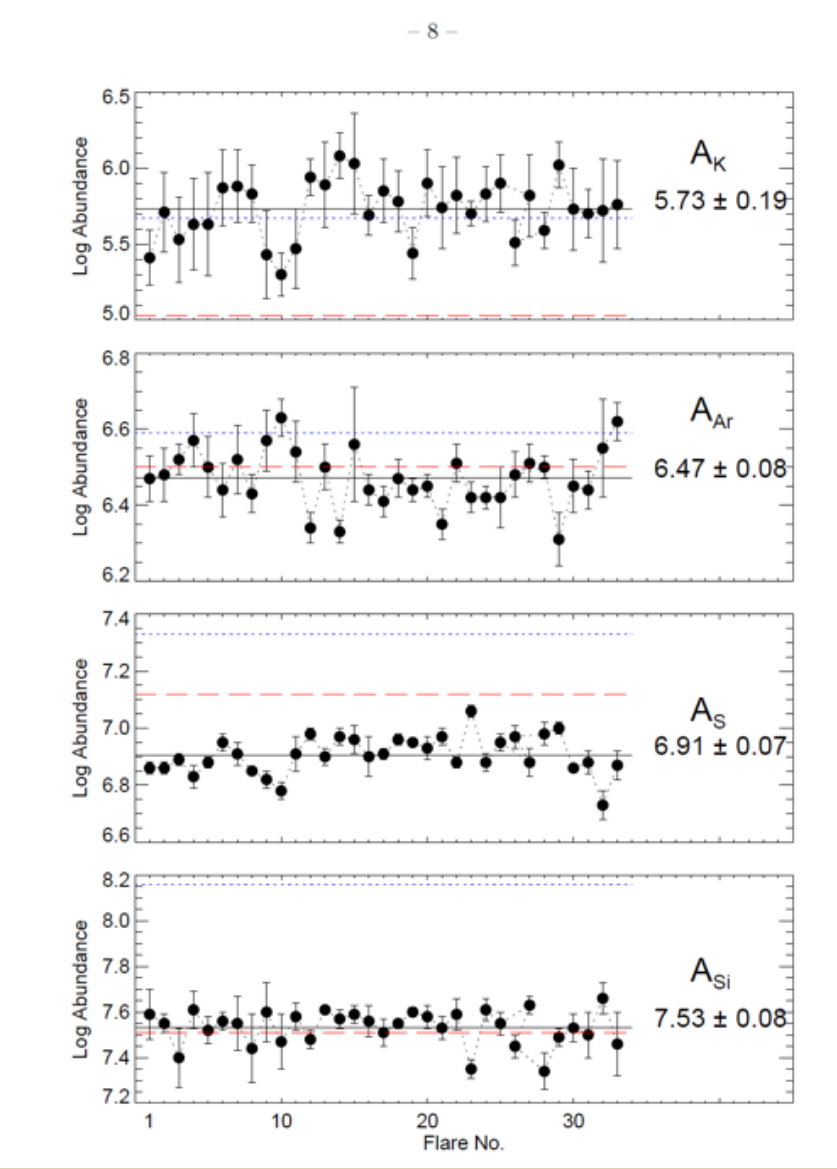






The three examples indicate for possible abundance variations during the flare evolution.

Results: Observed regularities



- K (FIP=4.34 eV) abundances usually much above the coronal value; but… should be regarded with caution (?) upper limit is reliable.
- Ar (FIP=15.76 eV) abundances: slightly below the photospheric (results in agreement with **isothermal** analysis).
- S (FIP=10.36 eV) abundances always below photospheric (inverse FIP effect?)
- Si (FIP=8.15 eV) abundances close to the photospheric value.
- Similar scatter Ar, S, Si, much larger for K, but….

Time averaged values with rms error bars: small changes from flare to flare are within uncertainties…

Coronal .....

Photospheric - - - - - - -

Concluding remarks

- For most of analysed flares the abundances do NOT change significantly during the flare evolution. The variations are within the estimated uncertainties, so the derived abundances seem to be constant over the flare for this sample of investigated moderate RESIK events. (33 flares: 1 of X, 5 of M class, 26 of C class, 1 of B class)
- There is rather little flare to flare variation of estimated values for A(K), A(Ar), A(S) and A(Si) abundances. Mean values ($\log A_H$)=12 with the event to event scatter are:
- enhancement (phot)

A(K) =5.73±0.19 5.0 ± 2
A(Ar)=6.47±0.08 0.93 ± 0.1
A(S) =6.91±0.07 0.62 ± 0.1
A(Si)=7.53±0.08 1.05 ± 0.2

No conclusive result in respect of abundance dependence on the flare location. Further analysis are needed.

- A(S)/A(Si)=4.19 2.45 (phot) enhancement ~ 1.7 (Brooks~2-3)

THANK YOU !!!!

Paper is under review ApJ

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References

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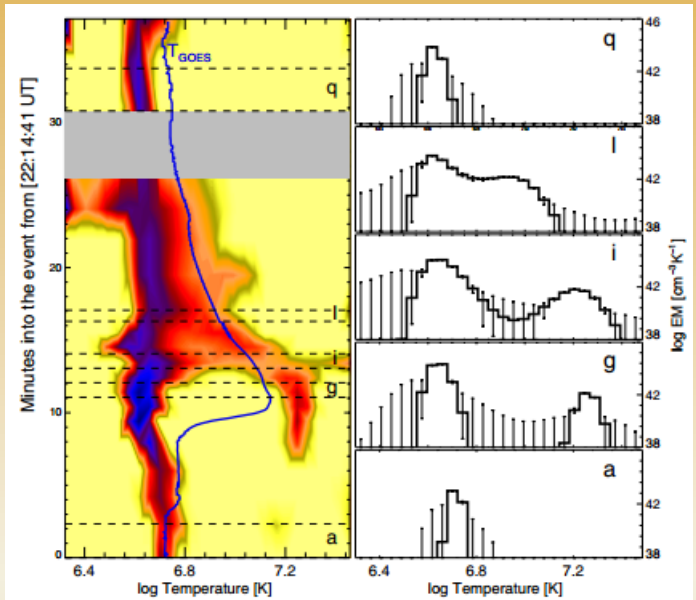
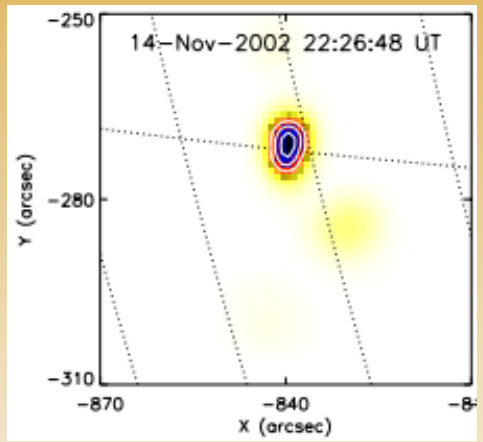
- Solar flare composition and thermodynamics from RESIK X-ray spectra; B. Sylwester, J. Sylwester, K. J. H. Phillips, A. Kępa, and T. Mrozek, 2014, ApJ, 787
- Plasma composition in a sigmoidal anemone active region; D. Baker, D. H. Brooks, P. Demoulin, L. van Driel-Gesztelyi, L. M. Green, K. Steed, and J. Carlyle; 2013, ApJ, 778
- J. Sylwester, J. R. Lemen & R. Mewe; 1984, Nature 310, 665 – 666
- J. Sylwester et al., ApJ. 501, 1998

Further analysis using determined abundances





Constant volume based on PIXON reconstructed *RHESSI* 6-7 keV images: 5400 km at 50% iso-contour → hot component parameters (N_e, E_{th})