Influence of Flare Iron Abundance on GOES XRS data interpretation

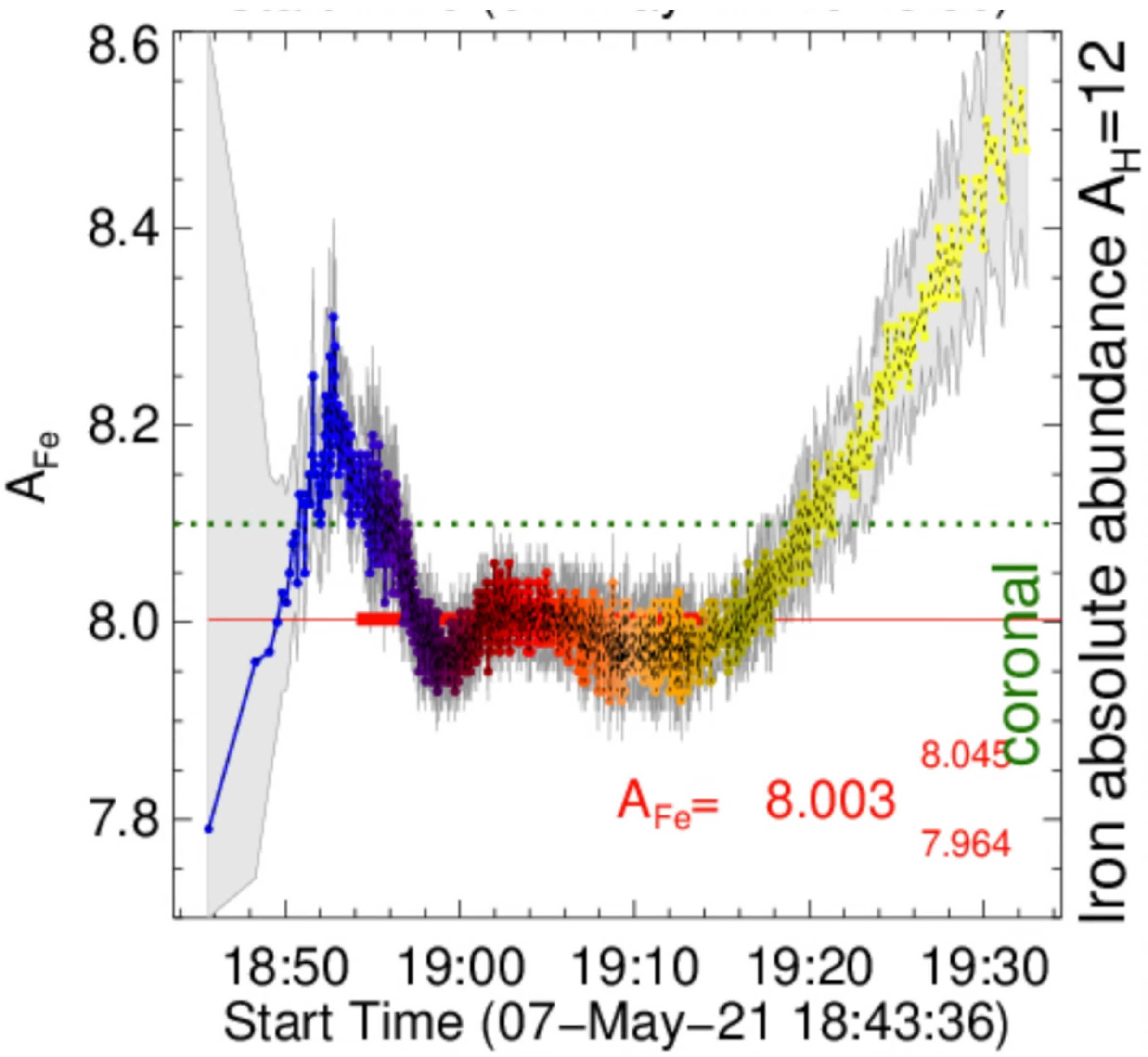
Janusz Sylwester, Karol Kułaga Barbara Sylwester,
and Anna Kępa

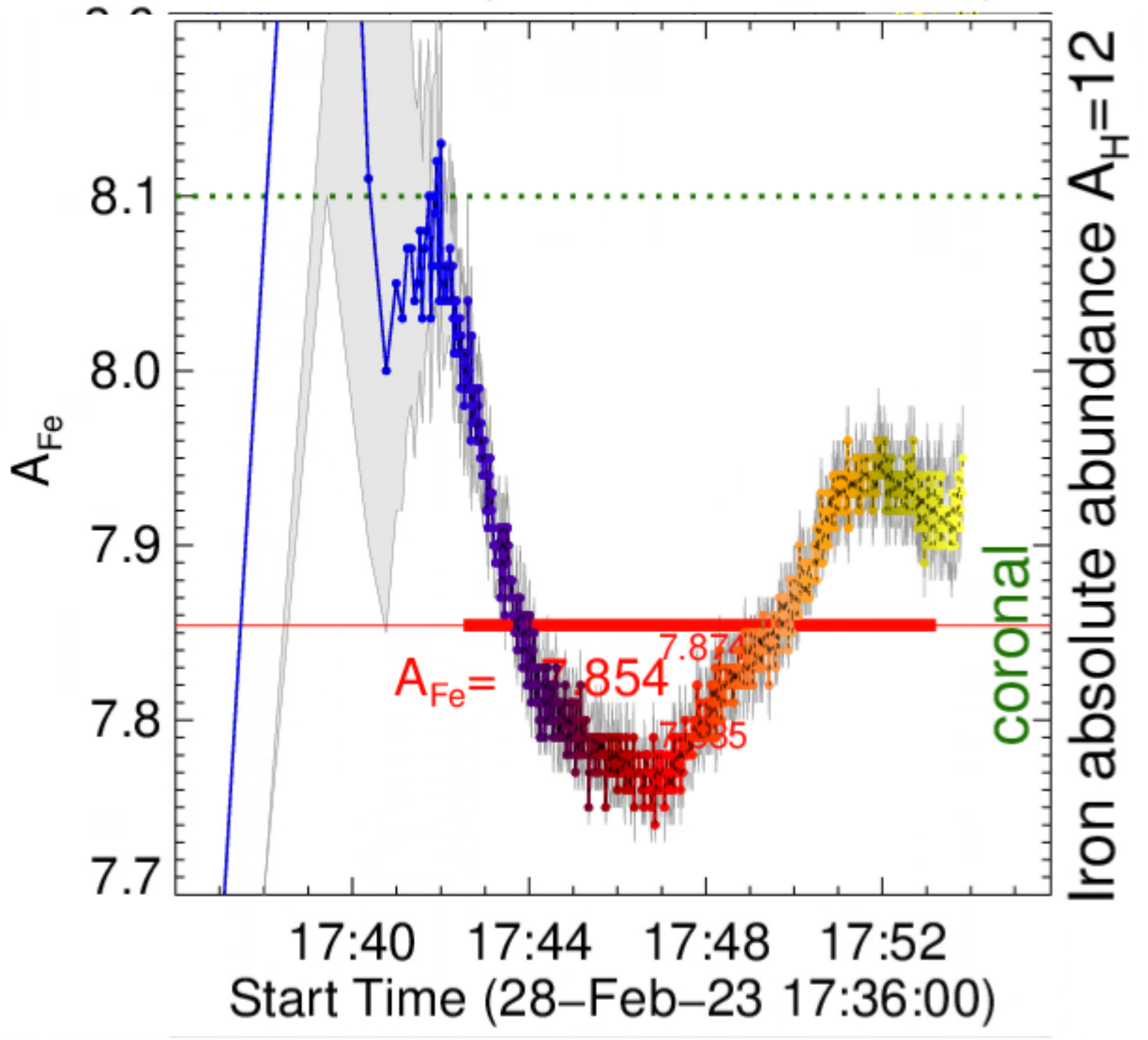
Space Research Centre, Bartycka 18a, Warsaw,
Solar Physics Division, Kopernika 11, Wrocław

Motivation and aims

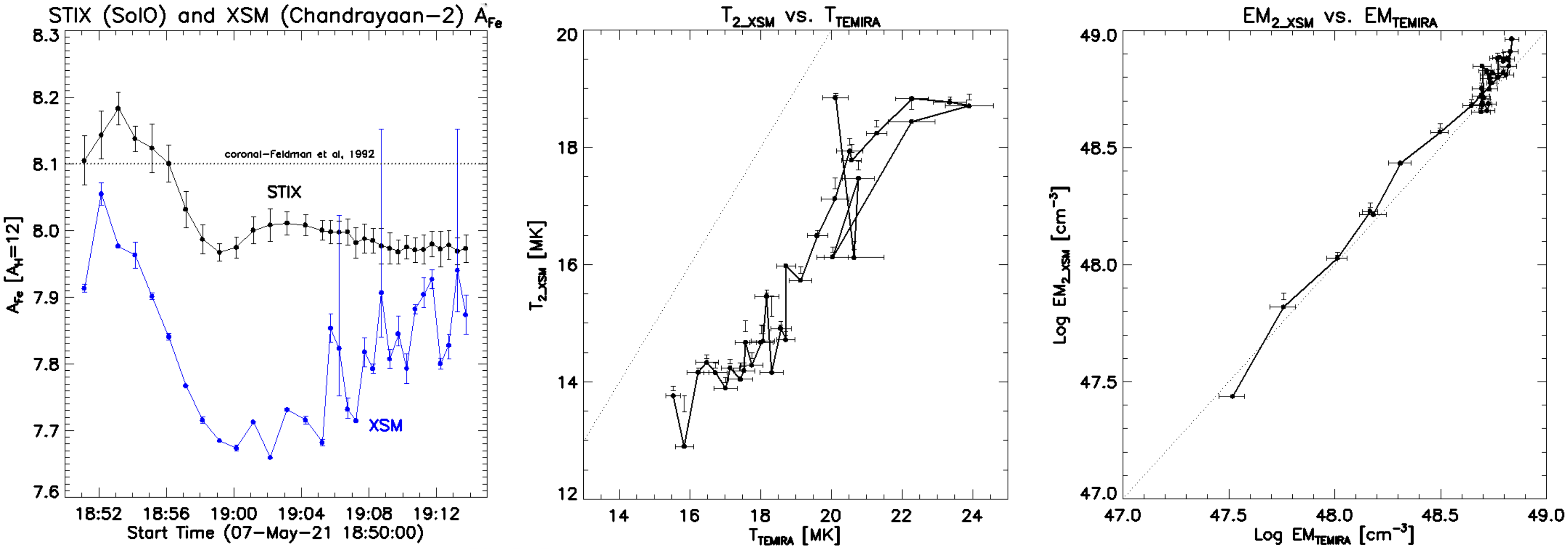
- Differences in plasma composition in flares and between AR is present "physical reality"
- TEMIRA (discussed on previous STIX Meetings) results reveal variations in flaring plasma iron abundance (A_{Fe} in a wide range 7.20 8.60), a factor of 25 difference, more than a difference between photospheric (A_{Fe} =7.47) and coronal (A_{Fe} =8.10)
- Using flare measurements by STIX and GOES (when commonly observed) will provide a deeper insight into temperature structure of flaring plasma (DEM distribution)
- SSW (at present, *goes*) interprets $GOES_{XRS}$ emissivities in 0.5-4 Å and 1-8 Å channels for two discrete abundance models only: photospheric & coronal

Examples of TEMIRA A_{Fe} behaviour





XSM Chandrayaan-2 spectra analysis indicate even larger amplitude of STIX variations for the same event



THE ASTROPHYSICAL JOURNAL LETTERS, 959:L29 (9pp), 2023 December 20 https://doi.org/10.3847/2041-8213/ad0f23

Investigations of Flaring Plasma Parameters during an M-class Flare Using the Differential Evolution Method and XSM/Chandrayaan-2 Observations

Anna Kępa, Marek Siarkowski, Arun Kumar Awasthi, Janusz Sylwester, and Barbara Sylwester
Space Research Centre, Polish Academy of Sciences (CBK PAN), Warsaw, Bartycka 18A, Poland
Received 2023 July 12; revised 2023 November 8; accepted 2023 November 22; published 2023 December 20

What was done

GOES-R Series X-Ray Sensor (XRS): 2. On-orbit measurements and calibrations

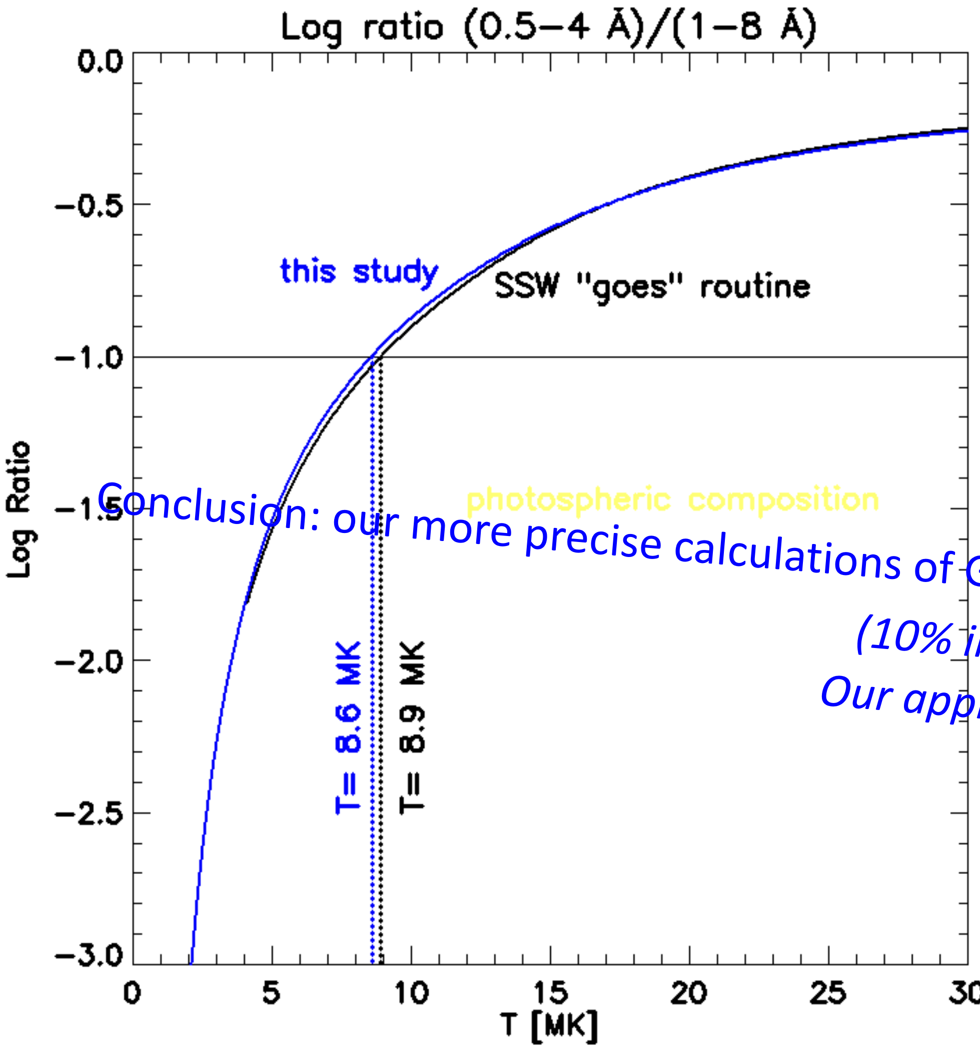
Janet L. Machol[1], Stefan M Codrescu[1], Courtney Peck[1], Elysia S. Lucas[1], James F. Mothersbaugh[1], Thomas N. Woods[2], Ann Marie Mahon[1], James Negus[3], Donald L. Woodraska[1], Thomas Eden[4], Francis G. Eparvier[2], Andrew Richard Jones[1], Brooke Kotten[5], Laurel Rachmeler[6], Andrew C. Wilson[1], Brian T. Kress[1], Juan V. Rodriguez[1], and Rodney A Viereck[7]

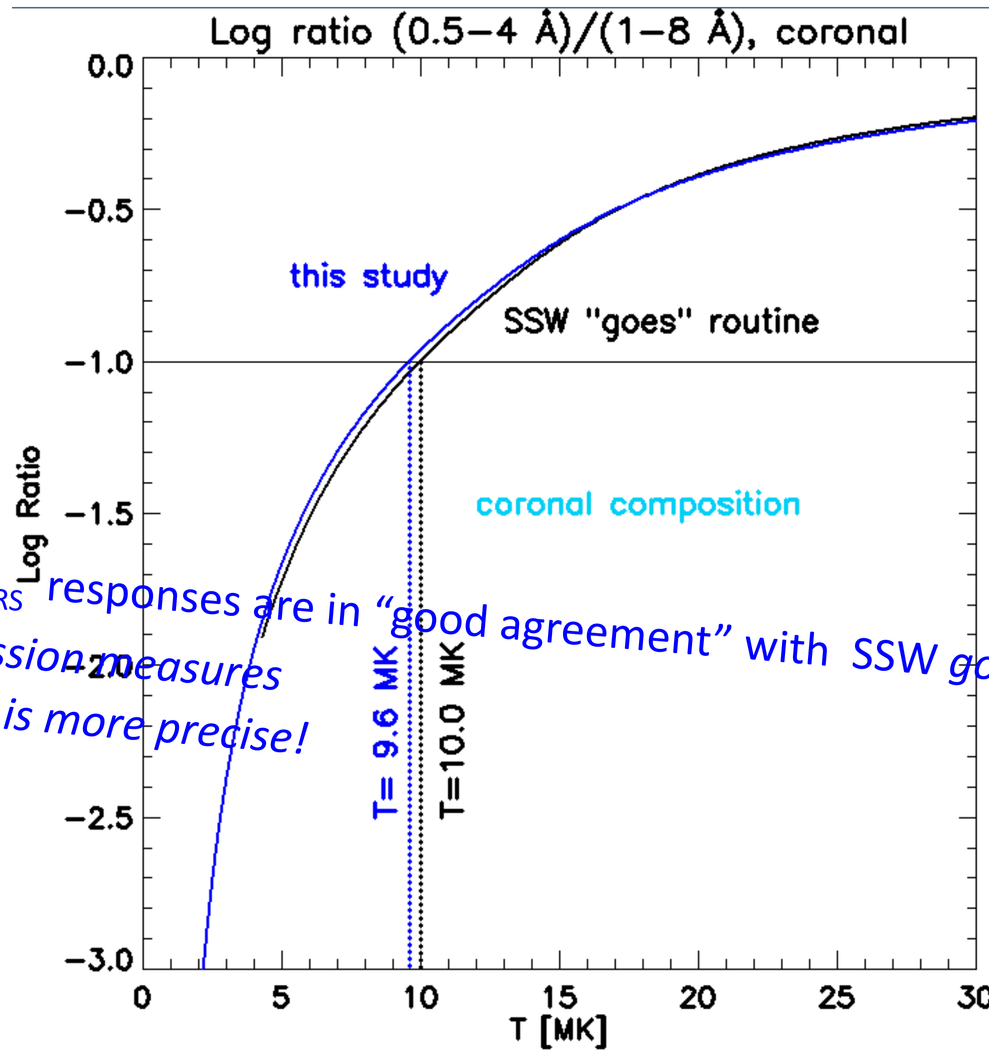
- We checked, how this varying plasma composition may affect results of analyses of $GOES_{XRS}$ (power in 0.5-4 Å and 1-8 Å channels) as made using the isothermal approximation
- We recalculated $GOES_{XRS}$ emissivities (from scratch) for photospheric and coronal composition models for GOES satellites 16, 17, 18 & 19. We used $GOES_{XRS}$ transmissions, as provided within SolarSoft (C:\ssw\gen\idl\synoptic\goes & https://www.ngdc.noaa.gov/stp/satellite/goes-r.html) covering (expanded) wavelength range 0.2-70 Å (0.18-62 keV) , wider than that used in SSW *goes* routine description. CHIANTI 10 was used, the same as in *goes*.
- SSW *goes* limitations: T is within 4.1-100 MK,phot. or coronal abundance models, while our is 2-100 MK, any abundance of iron
- Next slaids show how our “recalculated values” agree with the SSW results for temperatures T and Emission Measures (EM)

Panels comparing present and the standard SSW (as comes from *goes*):

photosperic

coronal



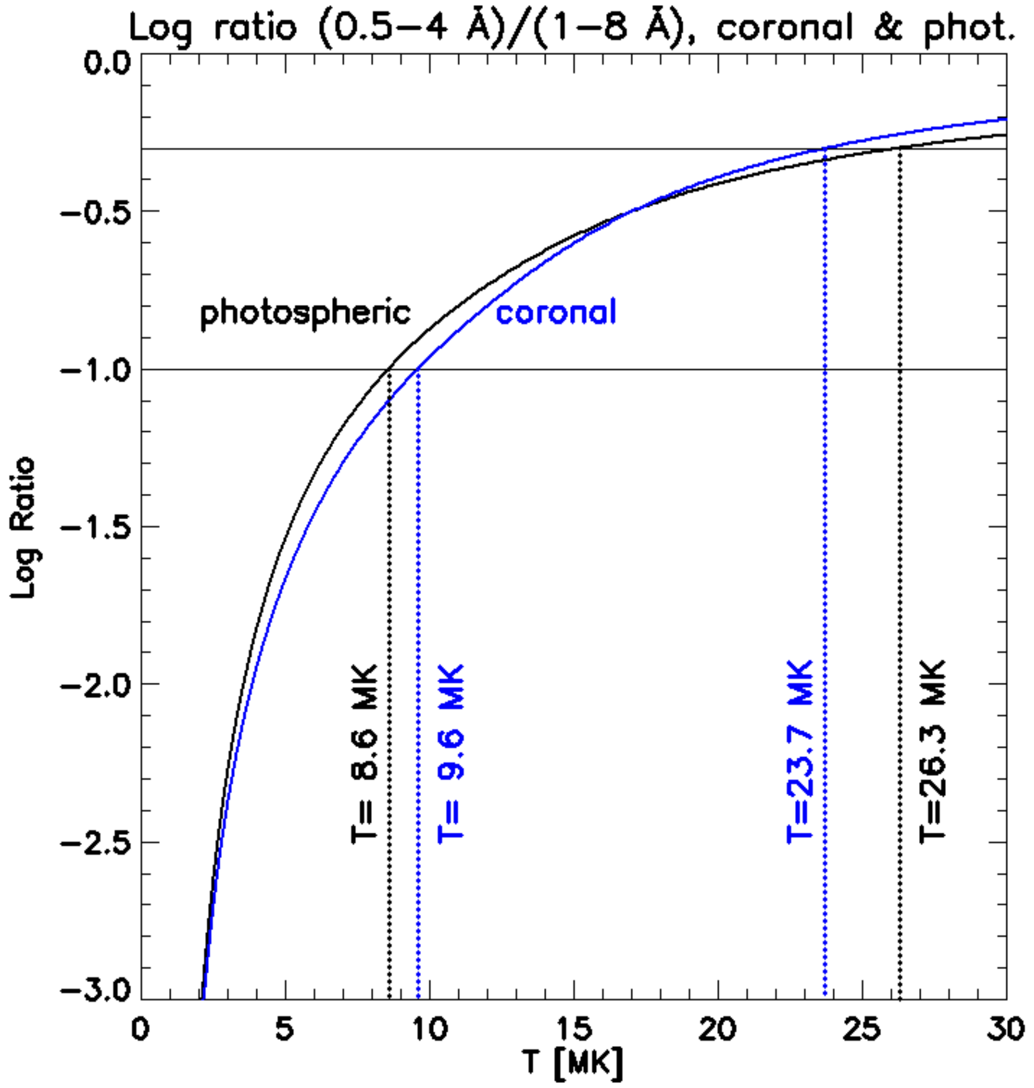


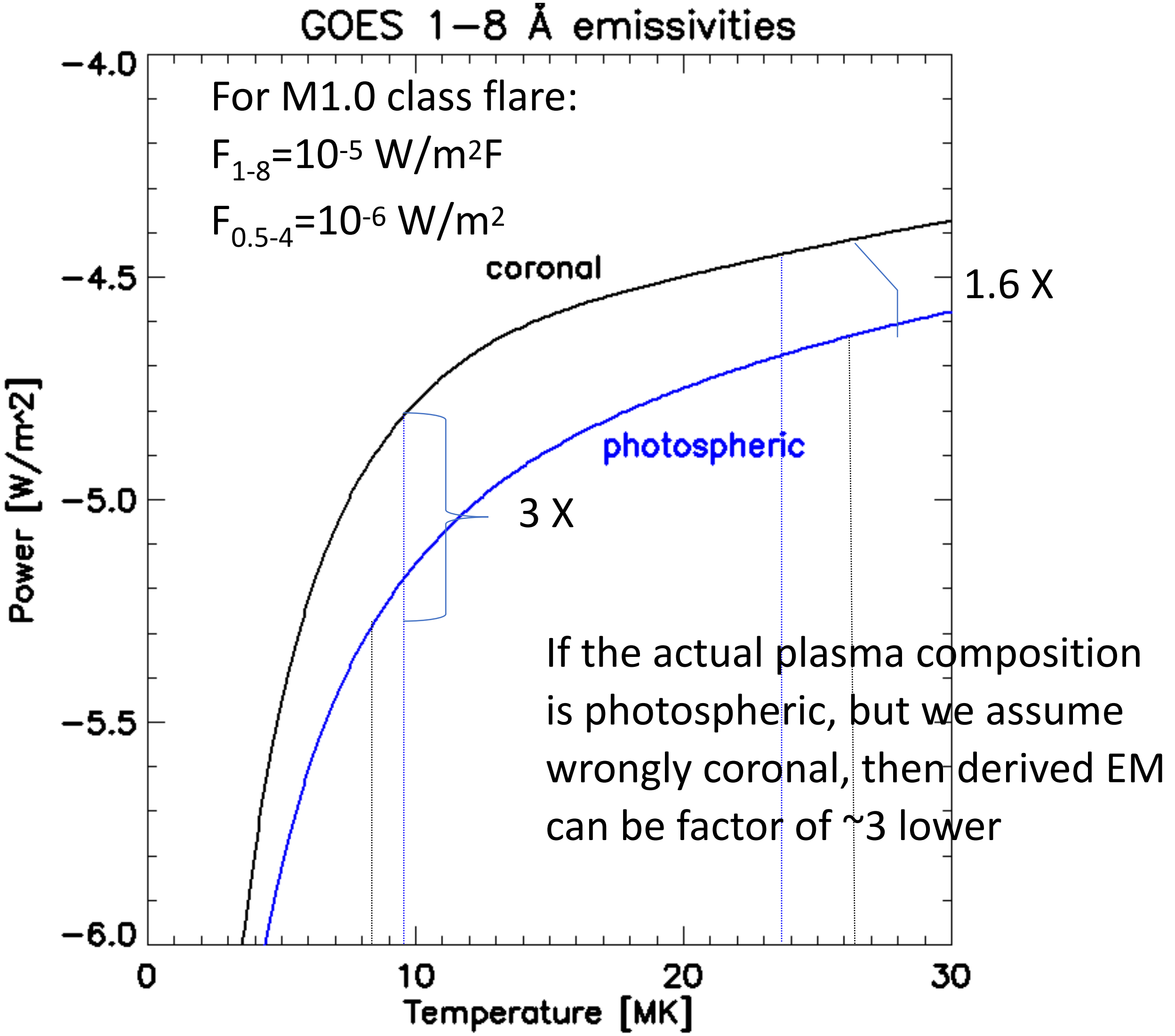
Conclusion: our more precise calculations of $GOES_{XRS}$ responses are in “good agreement” with SSW *goes*

(10% in emission measures

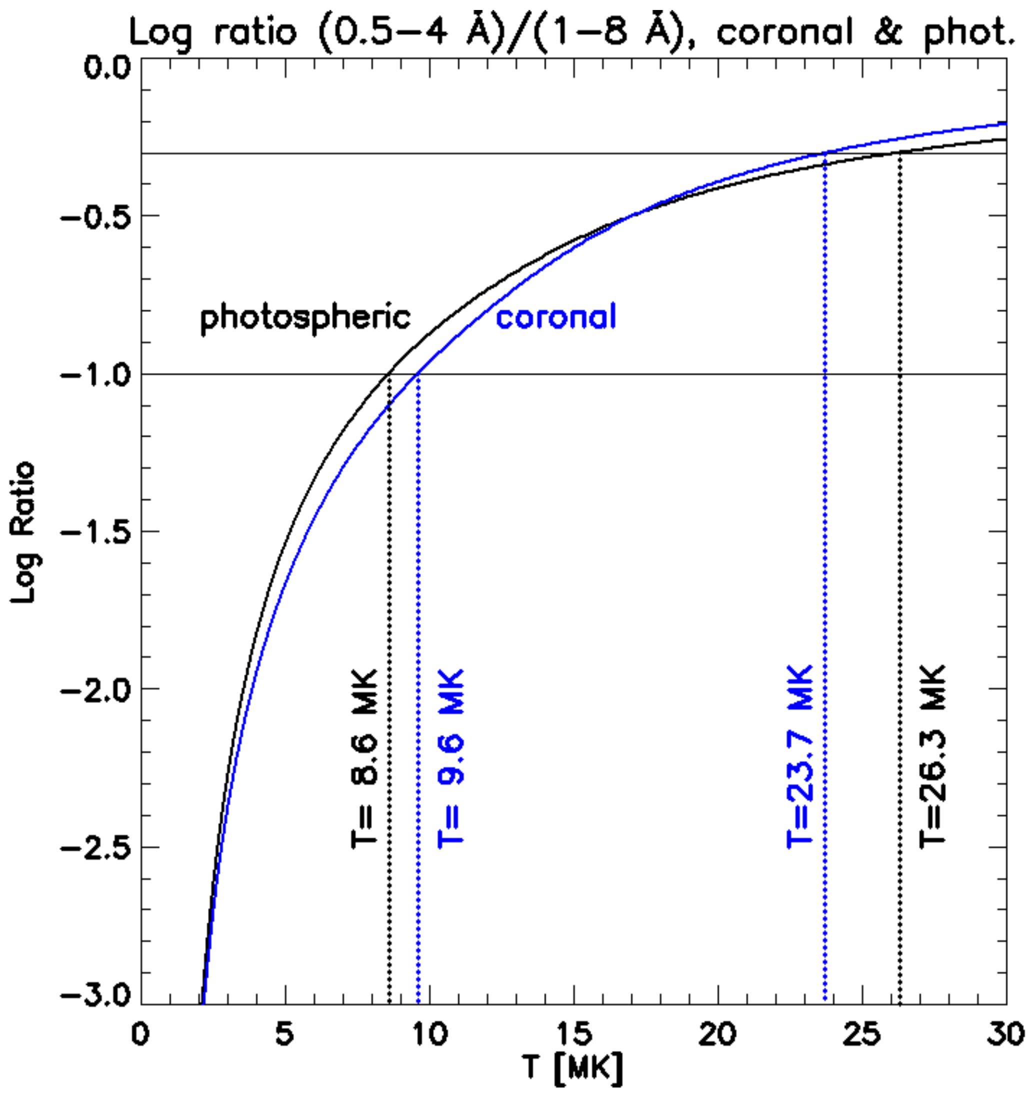
Our approach is more precise!

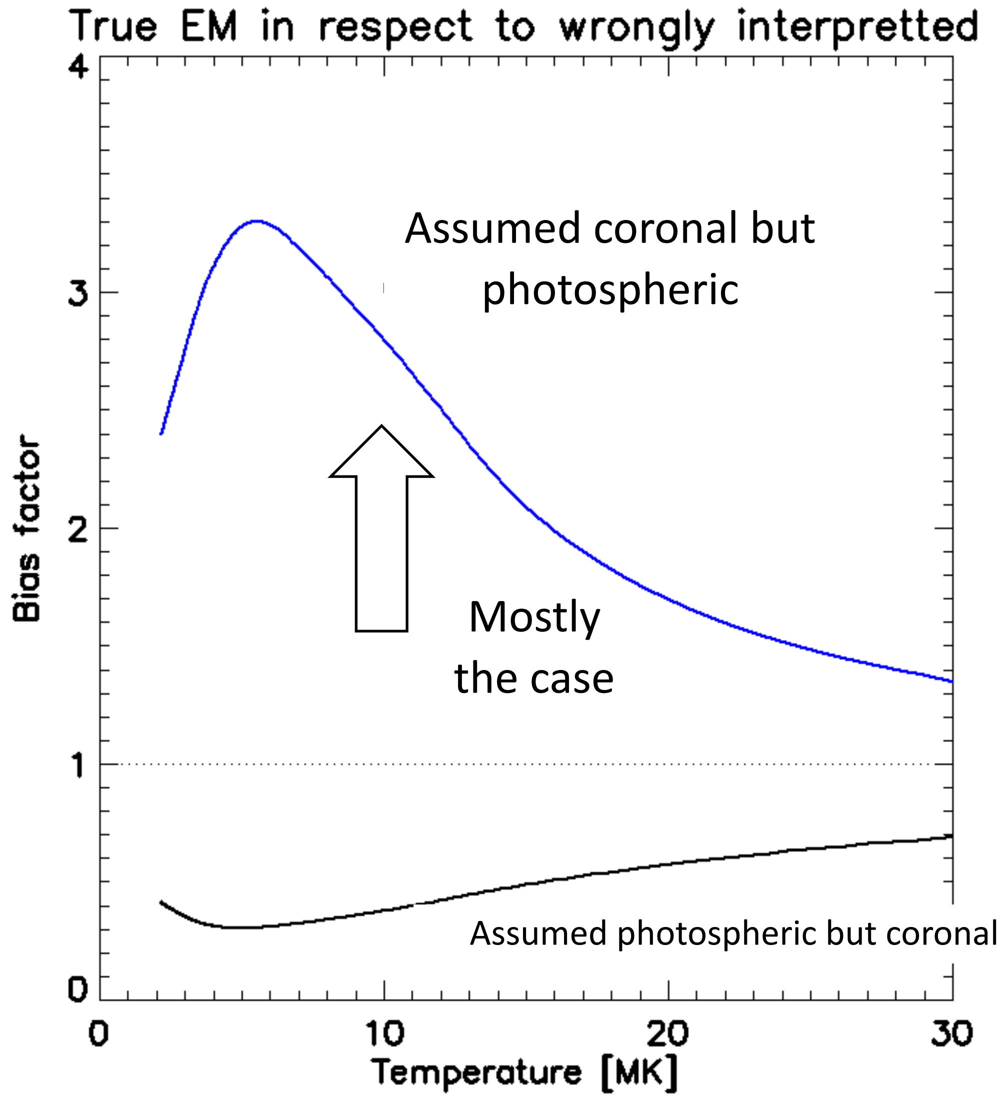
Let's check what may happen when we misinterpret the abundance: coronal vs. Photospheric: two example fluxes „observed" with the ratio 0.1, 0.5





Temperature dependent differences when we mis-interpret the abundance: coronal vs. photospheric

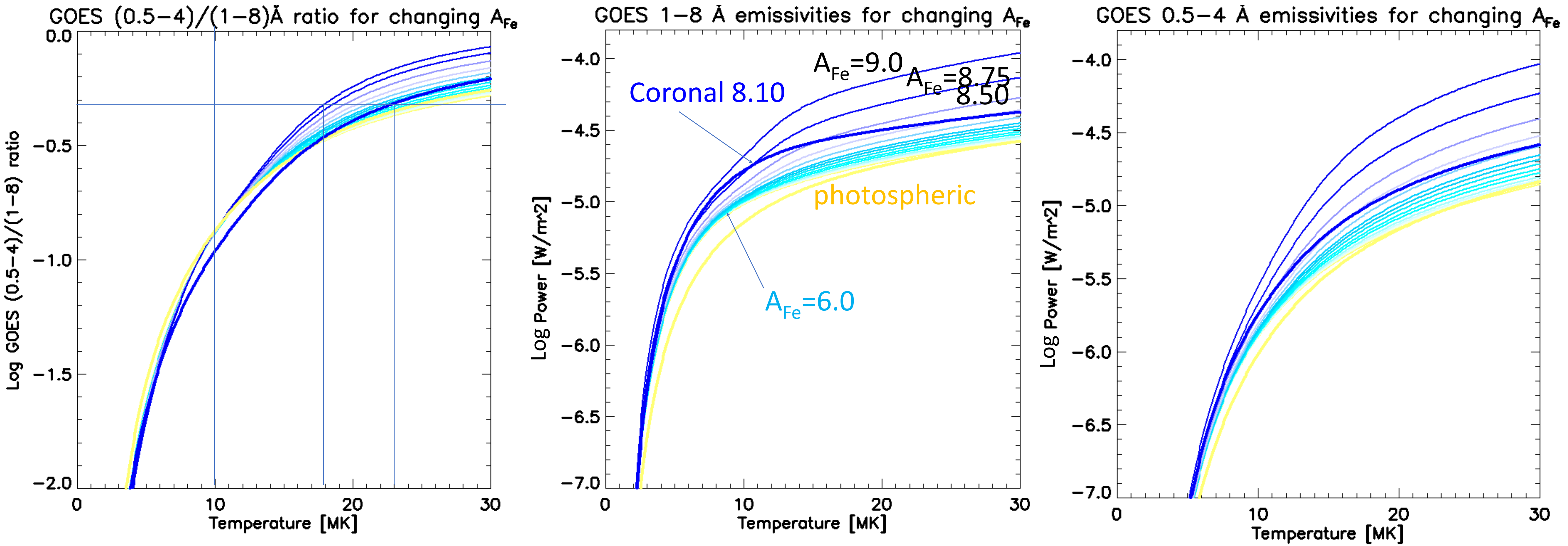




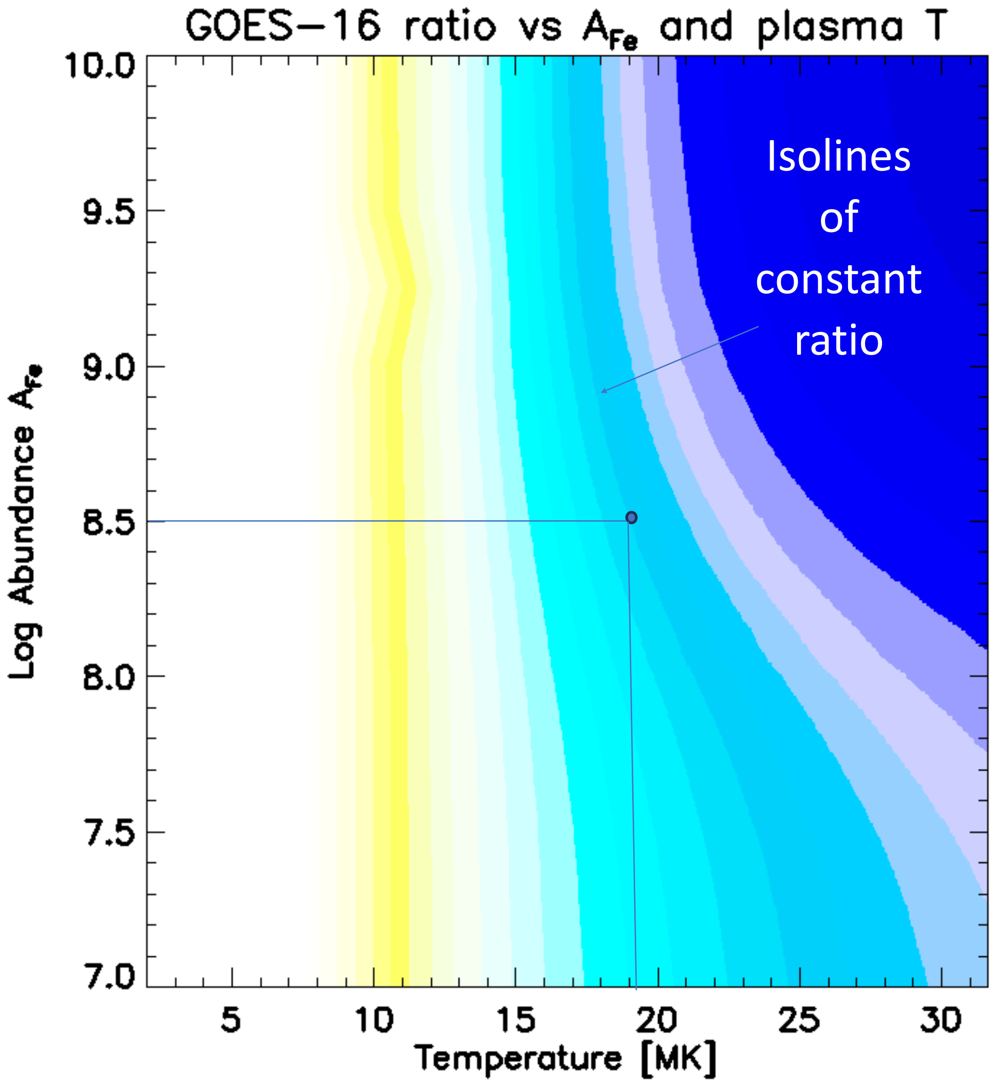
So, a need arrived at our Team to create "iron abundance" dependent "goes" fluxes interpretation package.
(to be further used in TEMIRA differential emission measure deconvolution)

- GOES fluencies in two standard bands are being used as entries, however the iron abundance is an optional extra parameter in the flux ratio interpretation.
- TEMIRA (or Three channel factor TCF-see later) provide actual A_{Fe} abundance values, so abundance-dependent GOES results (A_{Fe} ,T_{GOES}, EM_{GOES}) can be determined
- If XRS GOES and STIX measured fluxes are to be interpreted together for events commonly observed , TEMIRA A_{Fe} values are to be used for the emission measure estimates
- A routine in IDL (Py) is in preparation to address an A_{Fe} dependent "goes" data interpretation, based on spectra observed in the thermal range of five lowest energy STIX channels: 4-5-6-7-8-9 keV.
- This should eventually replace present SSW "goes" in realistic XRS data interpretation

An illustration of this computationally exhaustive calculations for GOES-16$_{XRS}$ responses for a range of iron abundances A_{Fe}



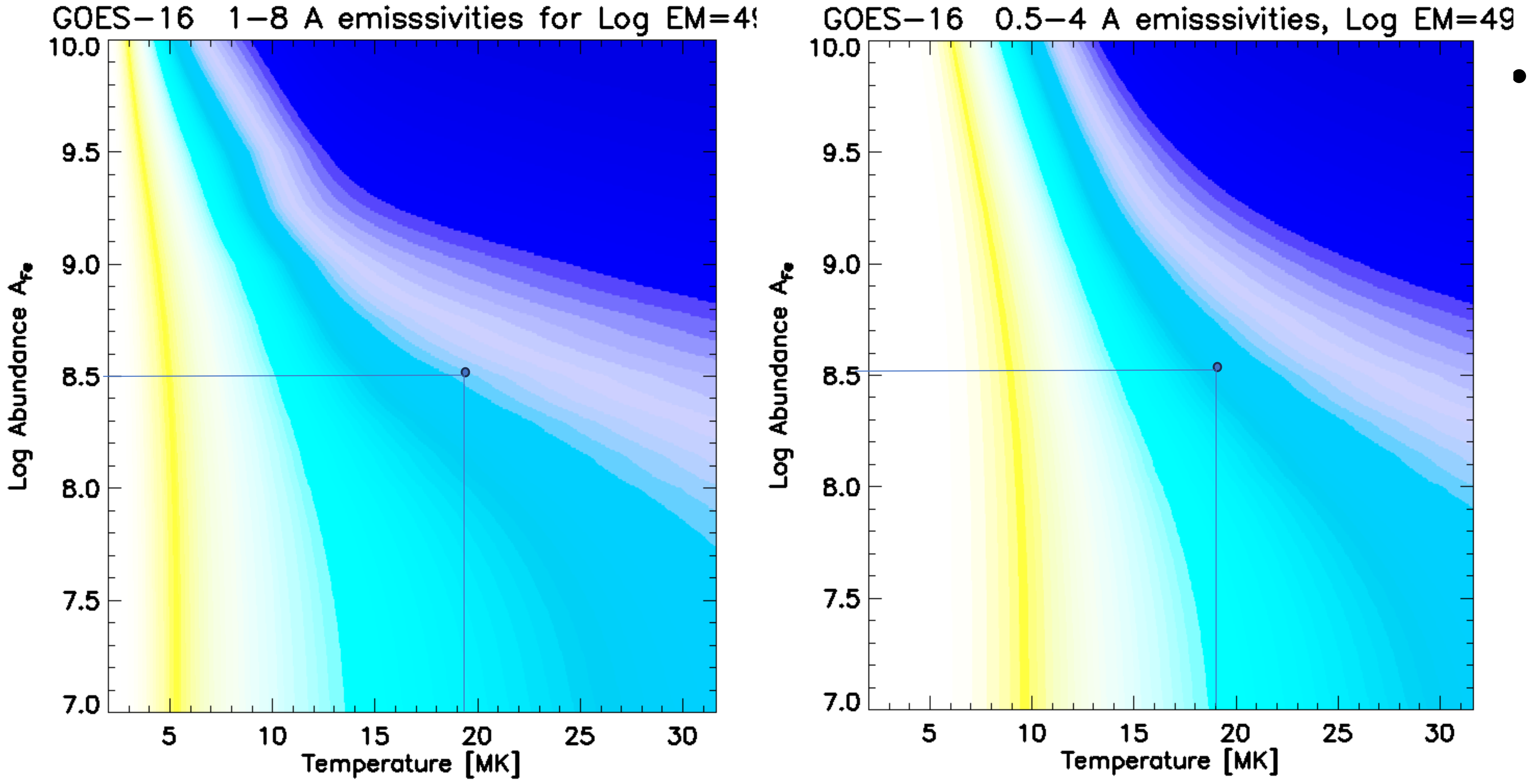
For practical reasons a higher "resolution" is necessary to work with the data: *goes_abu*



- goes_abu(19, A_{Fe} , f_{1-8}, $f_{0.5-4,}$[tst,ten])
  - [tst,ten] array of start & end times
- provide:
  - Tg, Tg_{low},T g_{up} in the range 2 – 100 MK, resolution 0.001 dex
  - EMg, Emglow, Emgup
  - A_{Fe} can be function of time, assumed constant between [tst,ten], in the range 6.0-11.0, resolution 0.001. dex
- For GOES: 16, 17, 18 & 19

and GOES-16 emissivities for EM=10^{49} cm^{-3}

similar patterns exist for GOES-17, 18 & 19



- EM is from the ratioof observed flux to predicted (for EM=$10^{49}$$cm^{-3}$) i.e. the reference EM used for simulating CHIANTI 10

What is next?

- Use abundance-dependent GOES emissivities to study DEM flare evolution by combining data from STIX and GOES in Temira_Goes DEM package (slaid after next)
- Make **goes_abu** available in SolarSoft (Karol Kułaga) and python (Agnieszka Kopacz).
- Work on version of **goes_abu**, where time-dependent "abundance **vector** for all important elements" can be set and used to interpret GOES data together with knowledge on changing elemental composition:
  - Chandrayaan-2. (Kepa et. Al. 2025,)
  - Aditya-1
  - CubiXSS (Caspi et al, in preparation, launch Feb.15 2027))
  - SUNSTORM 1/XFM-CS (Takala et al. 2025)
  - SDO (Woods, 2026) and
  - ALL studies where GOES EM is used to compare with!!!

Solar Physics (2026) 301:28
https://doi.org/10.1007/s11207-026-02618-0

RESEARCH

How Good Are GOES XRS Temperatures and Emission Measures?

Stephen M. White[1] · Darius Desnoes[2]

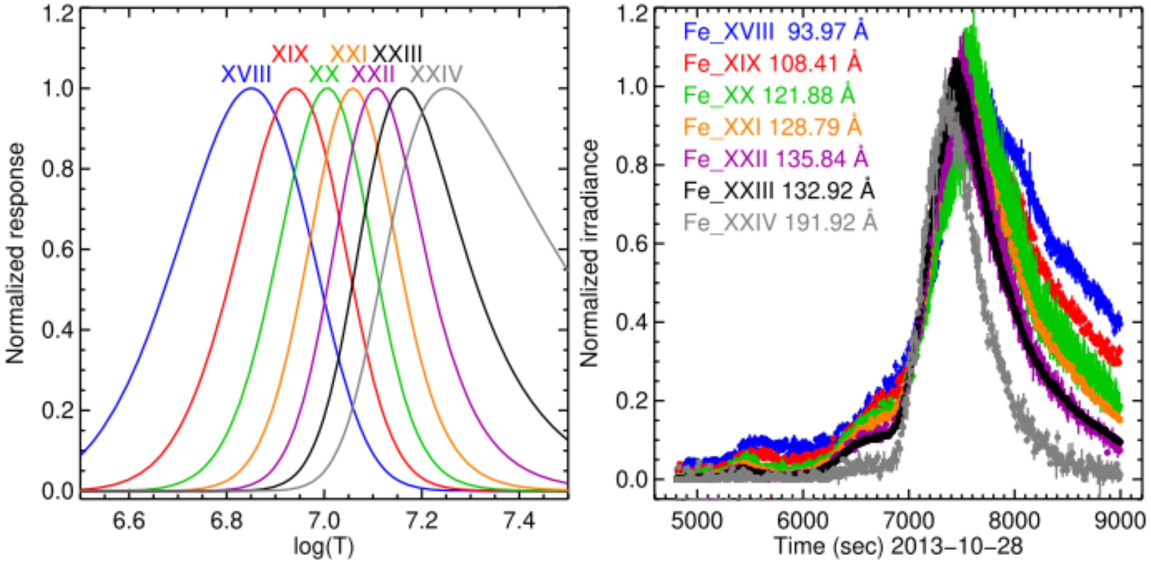


Figure 2 (Left panel) The normalized responses of the Fe XVIII – XXIV lines used for analysis. Note that these are the responses of the specific lines of the given charge state, not the responses of the fitted lines which include temperature-dependent blends. (Right panel) The fitted irradiances of the flare lines in the 2013 October 28 X1.7 flare as a function of time: each point represents a 10-second integration from the EVE Level 2 data. One-σ error bars are plotted on all points.

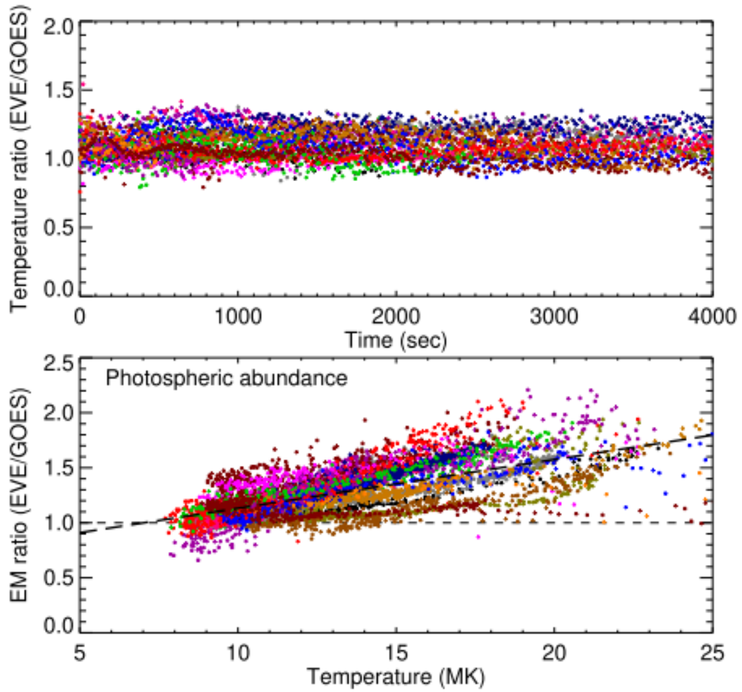
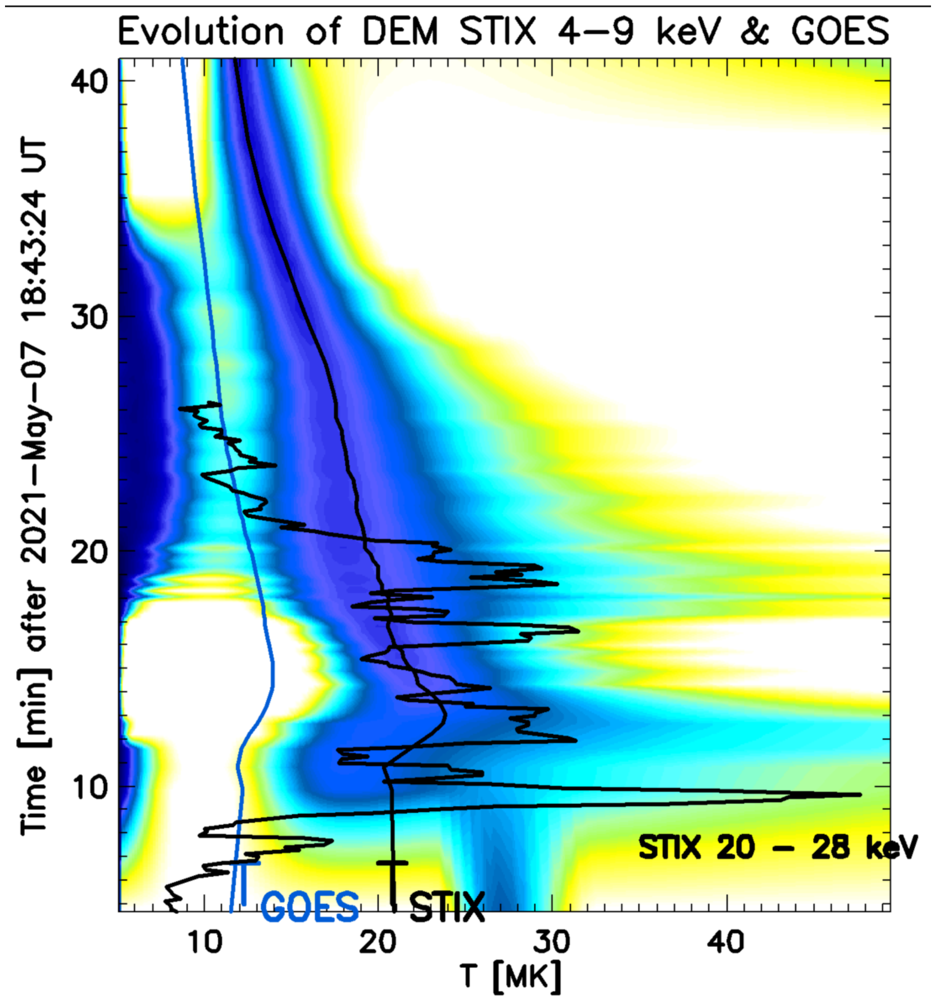
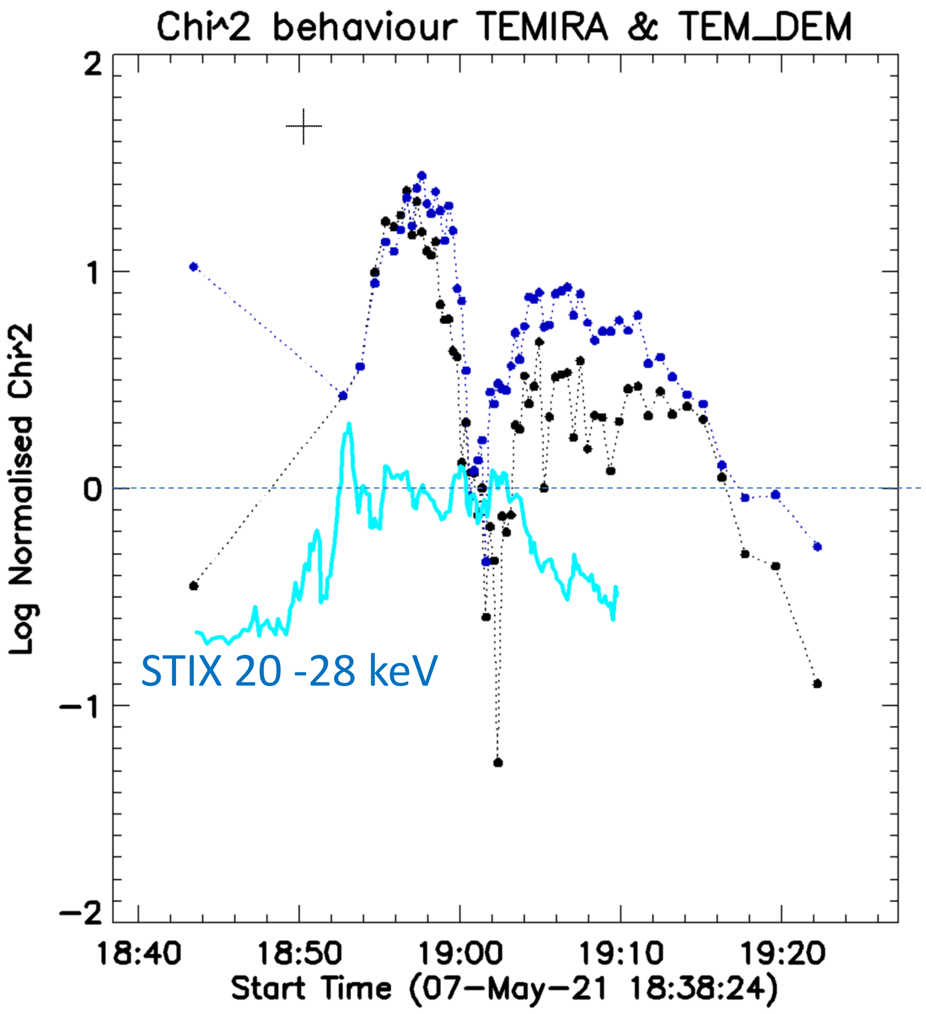


Figure 7 Plots of the ratio of the EVE DEM-weighted flare temperature to the GOES XRS temperature as a function of time (upper plot) and the ratio of the EVE total emission measure (EM) to the GOES emission measure as a function of EVE DEM-weighted temperature (lower plot) for 20 of the 23 events listed in Table 1. The flares of 2011 November 5, 2014 February 4 and 12 were omitted because their EMs never exceed 10^{50} cm^{-3} and the corresponding values are much noisier than the stronger flares. The GOES 2-second data have been rebinned to match the EVE 10-second samples. For each flare data are plotted where the EM exceeds 10% of the maximum for the flare, and each flare is plotted with its own color. A total of 6420 10-second samples are plotted. In the upper plot the time range is limited to 4000 seconds from the point where the EM first exceeds 10% of the flare's maximum EM. The dashed line in the lower panel is a linear fit to the data.

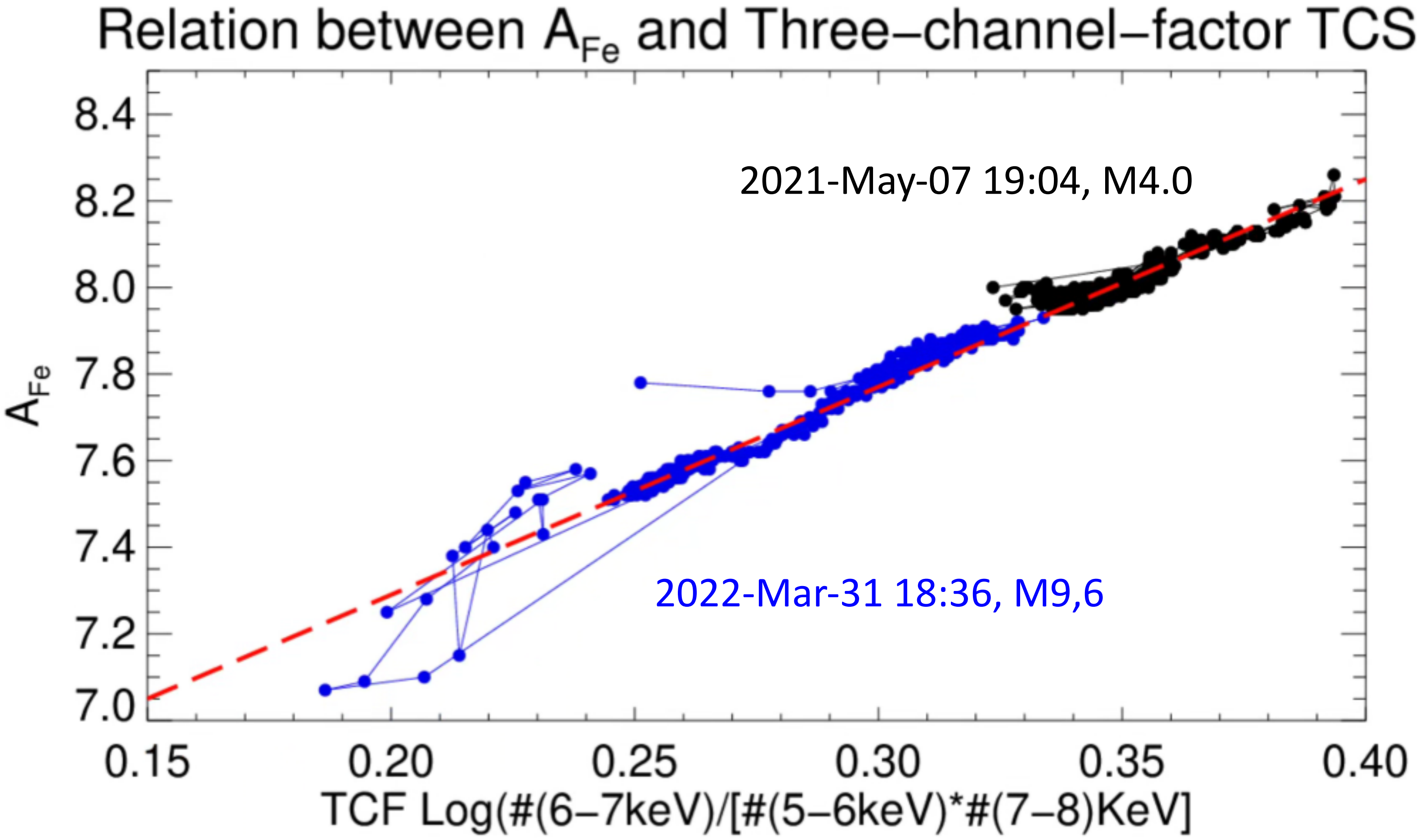
Our goal: common STIX & GOES DEM analysis





- 5-50 MK range
- Modified Max Likelihood algorithm (W-S)
- 30 000 iter
- A_{fe} as determined from TEMIRA

Proxy for iron abundance: Three channel factor TCF: (6-7 keV)/((5-6 keV)*(7-8 keV)



- Nearly always available in the spectroscopy mode -for most of (10^5) flares?? A new parameter characterizing hot plasma at each time
- Three channel maps --> abundance mapping, channels 5-6-7-8 contain the most of flux (for flares) and their TCF represents iron abundance

Thank you !