TEMIRA: alternative processing of STIX (pixel) spectra in order to determine T, A_{Fe} & EM a novell approach

Janusz & Barbara Sylwester
Karol Kułaga & Arun Kumar Awasthi

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

Motivation:

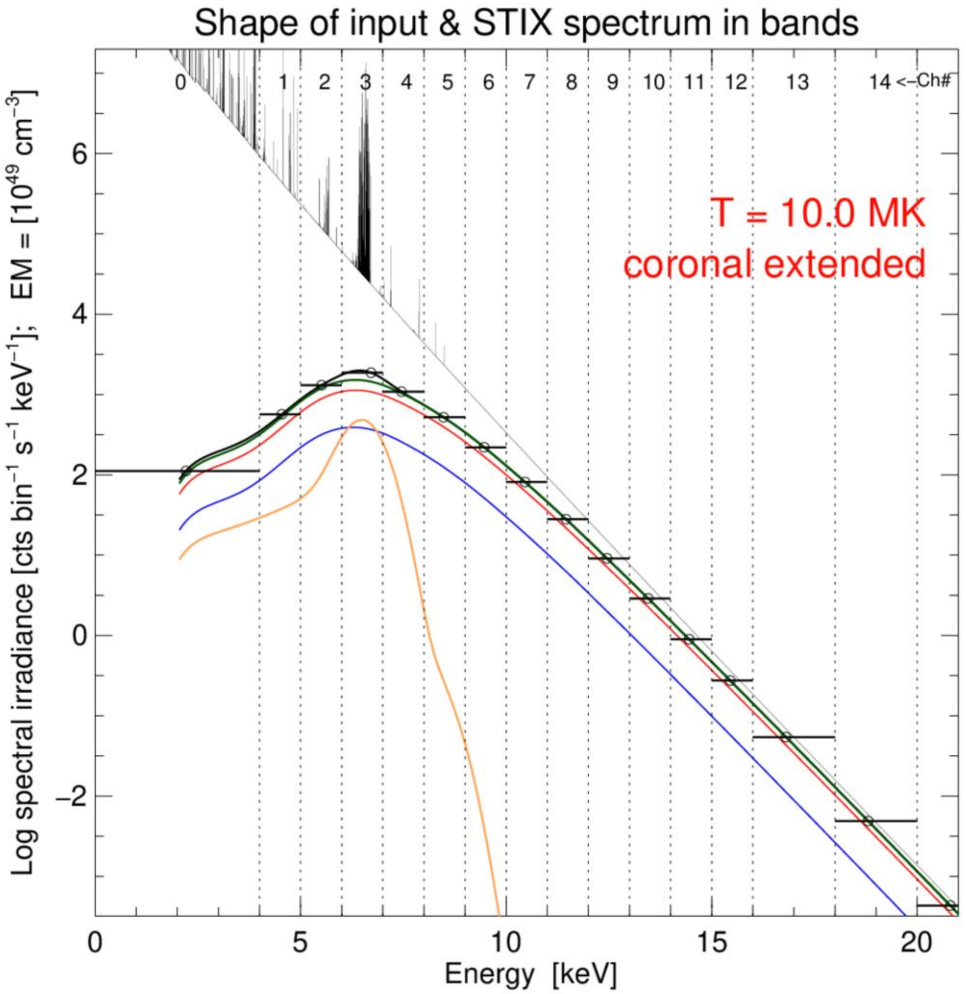
Study the evolution of flaring plasma characteristics: **T, A_{Fe} & EM** from STIX spectra in its lowest-E channels at the highest time resolution (down to 0.5 s)

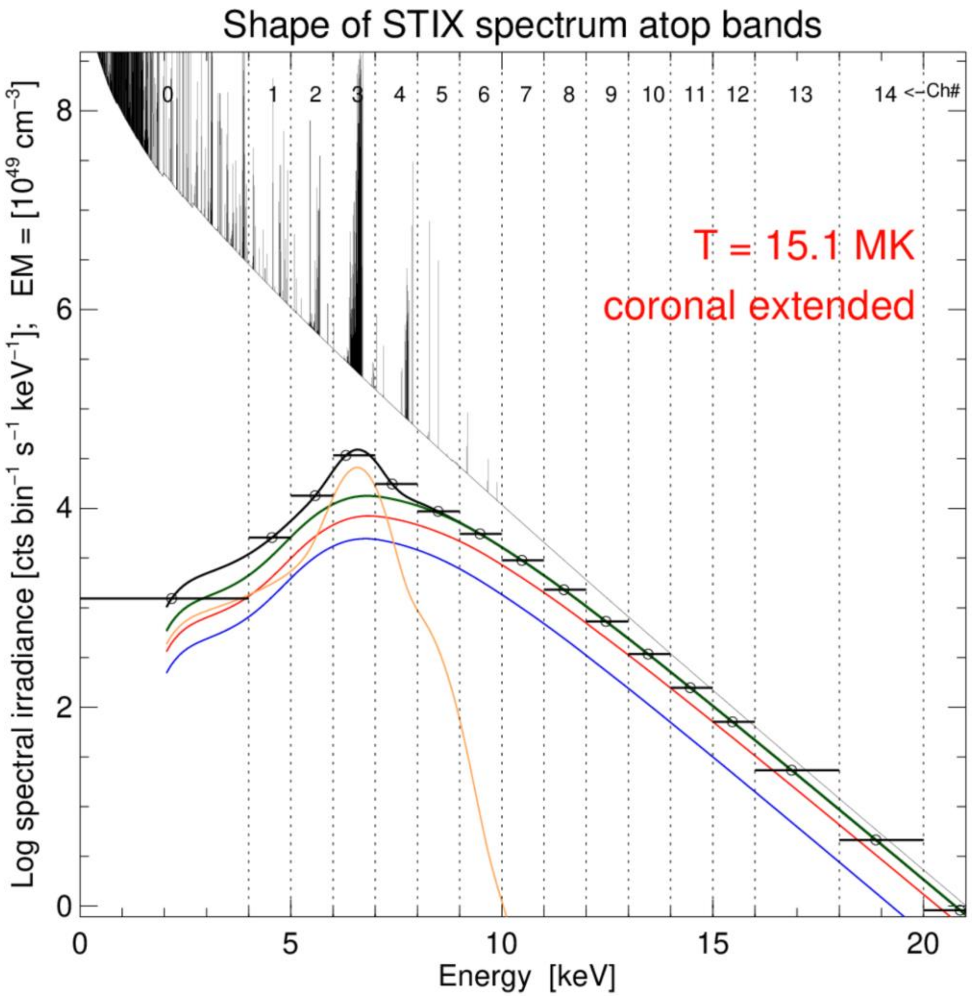
- We make use of information contained in a rich count-rate signal of high cadence records (0.5 - 1s) coming from detector integrated pixel spectra (30 imaging).
- We are using a new approach called TEMIRA (OSPEX independent) for determination of flaring plasma (iso) thermal component characteristics
- TEMIRA stands for temperature & iron abundance determination algorithm eliminating emission measure

Calculation the theoretical responses of STIX channels for plasma of various iron abundance

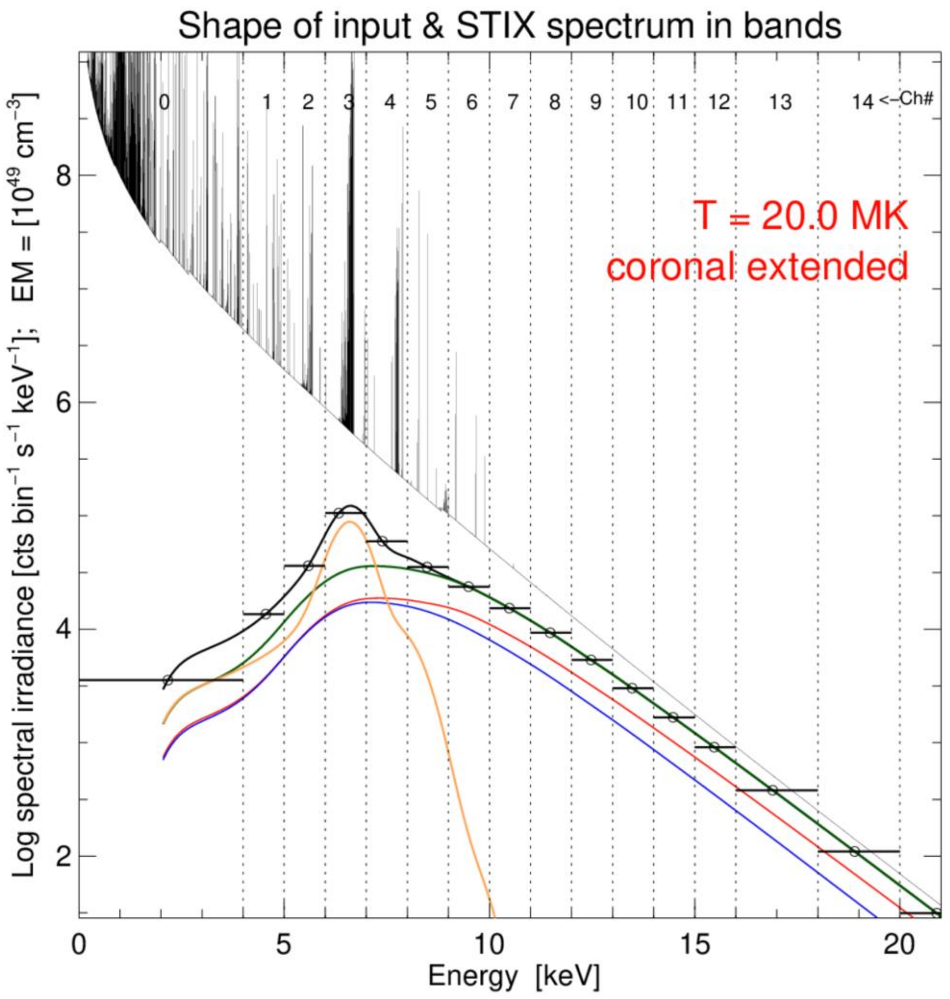
- CHIANTI v10 was used as convenient package, slightly modified to output individuals atomic processes contribution
- Details of CHIANTI calculations: isothermal plasma of temperature T in the range $10^5 - 10^8$ K (dex=0.02, 151 values, STIX useful range above 2 MK implemented)
- Assumed (27) elemental abundance models A_{Fe} (log A_H =12) varying from 0 to 11, ([0.00,6.00,6.25,6.50,6.75,7.00,7.25,7.50,7.65,7.80,7.91,8.00,8.15,8.30,8.50,8.75,9.00,9.25,9.50,9.75,10.00,10.25,10.50,10.75,11.00,7.47,8.10]); other elements' abundances taken from RESIK determinations for the corona (25 sets). In addition photospheric Scott and Coronal_extended abundance models included (last two entries)
- **New response matrix** (**Ewan Dickson**, May 2023 – DRM: 1054 x1054) as determined following discussions during the last Prague STIX meeting)
- Nominal width of the five lowest STIX Energy channels used: **4 -5 - 6 – 7 – 8 – 9 keV** where the influence of iron line complex contribution is high/noticeable (narrower bands observations are in the analysis)

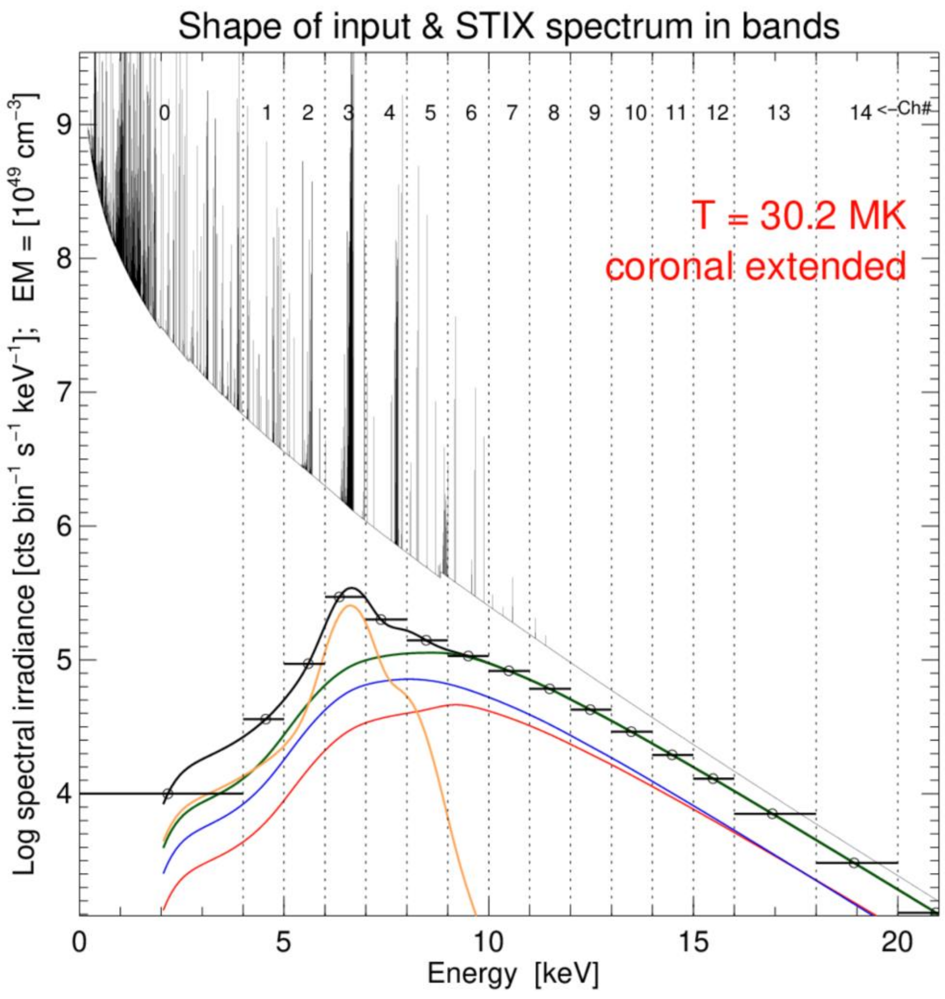
Example calculated STIX spectra for T=10.0 & T=15.1 MK



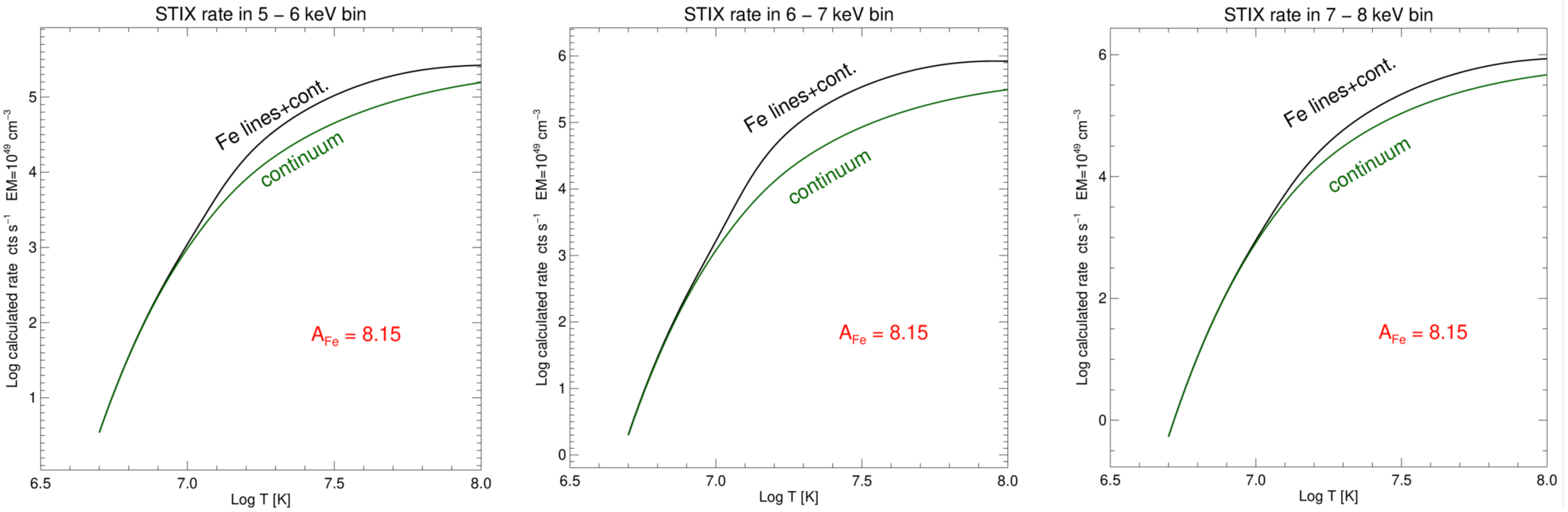


Example calculated STIX spectra for T=20.0 & T= 30.2 MK

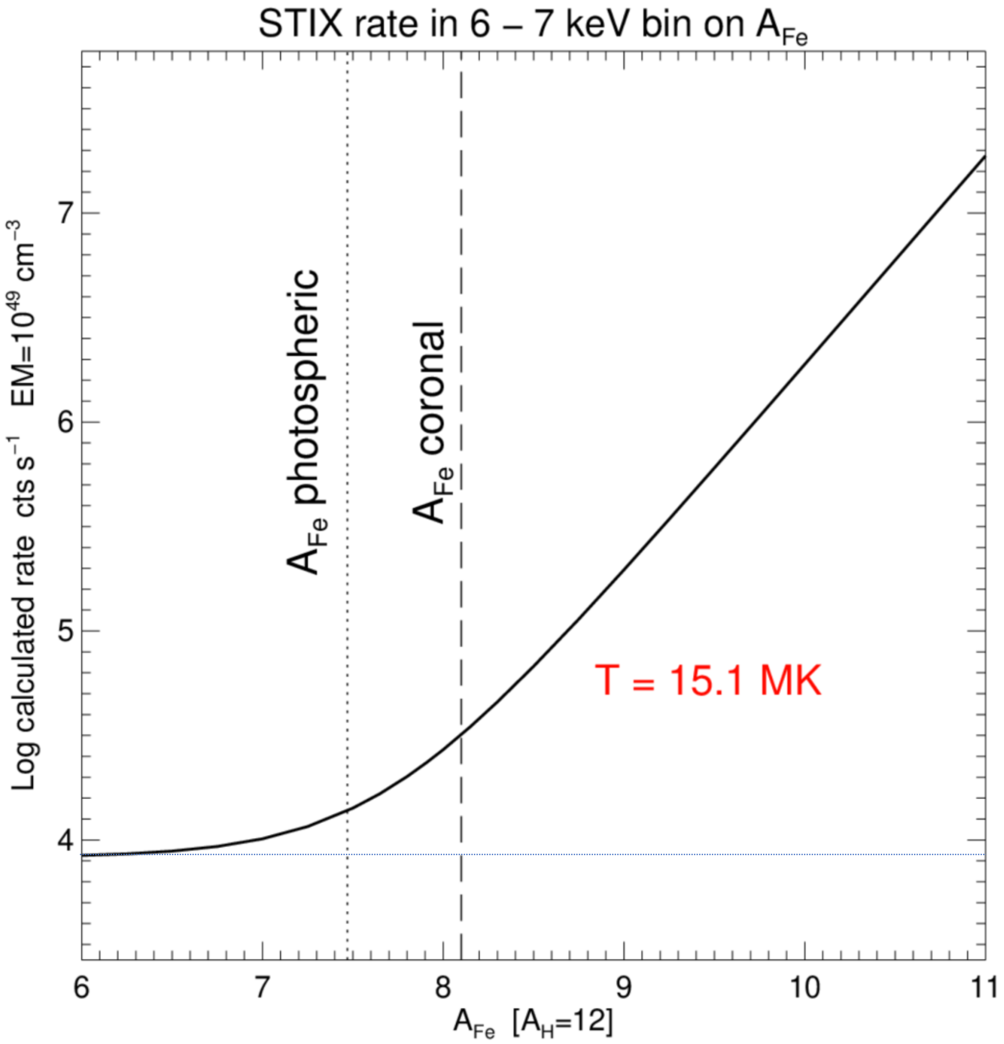


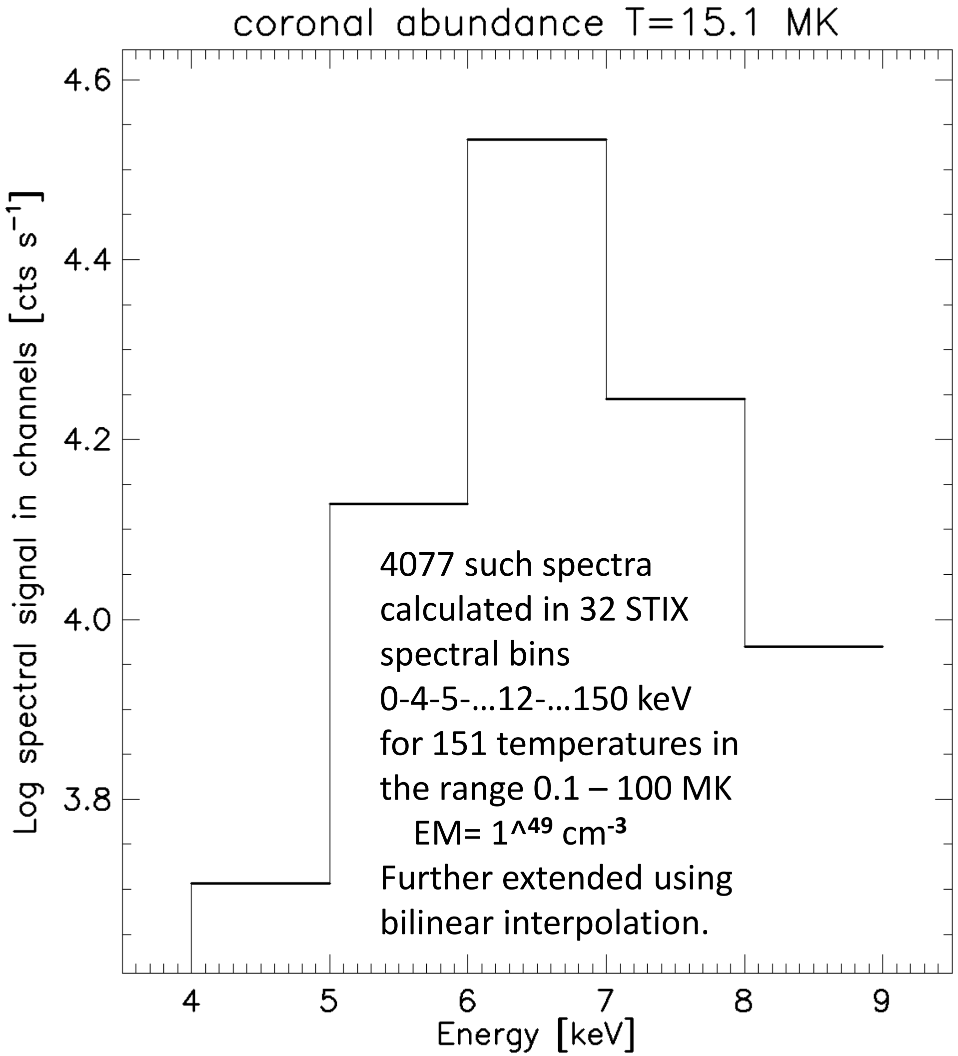


Behaviour of calculated fluxes in various energy bands $A_{Fe} = 8.15$



Strong dependence of 6 -7 keV band rate on A_{Fe}



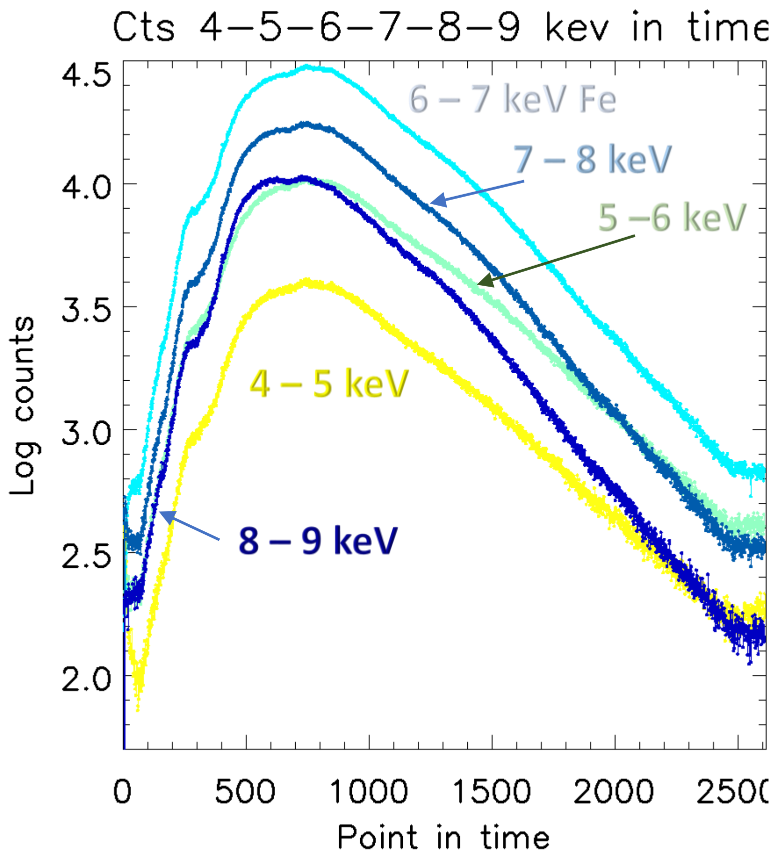


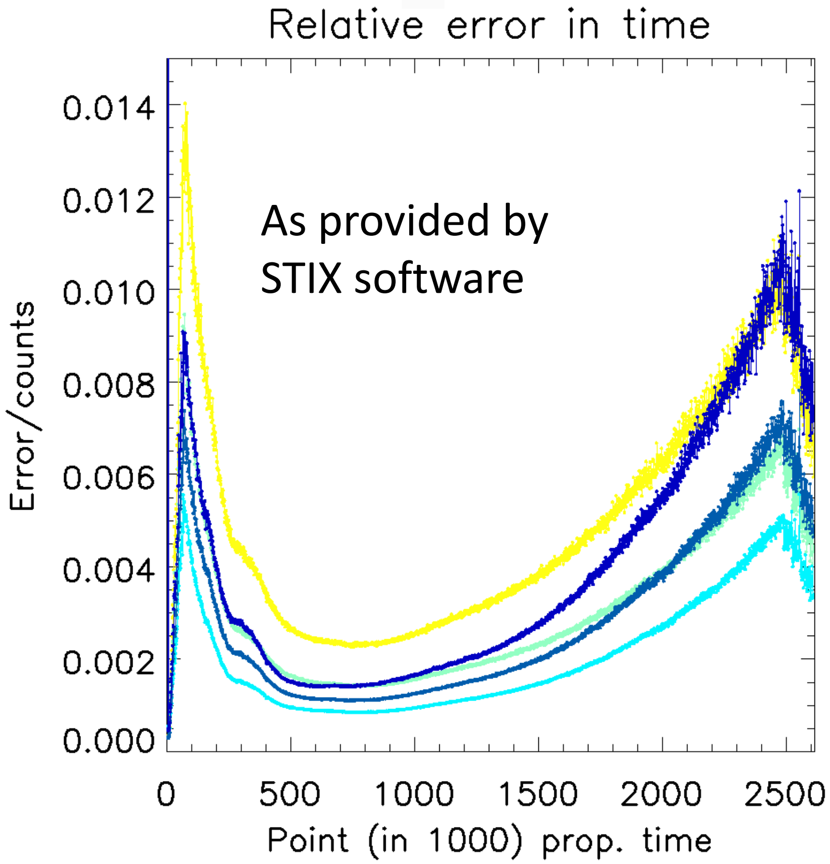
4077 such spectra calculated in 32 STIX spectral bins 0-4-5-…12-…150 keV for 151 temperatures in the range 0.1 – 100 MK

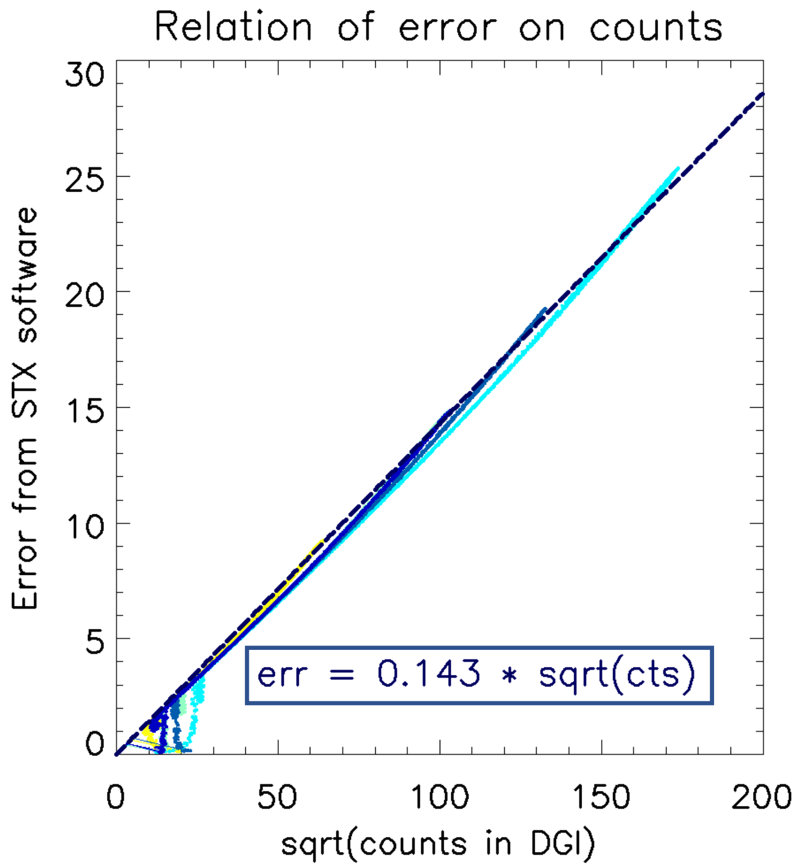
EM= $1^{\wedge 49}$ cm^{-3}

Further extended using bilinear interpolation.

Simplified treatment of uncertainties 4-5-6-7-8 keV channels (flare of 7th May 2021 ~19:00 UT)

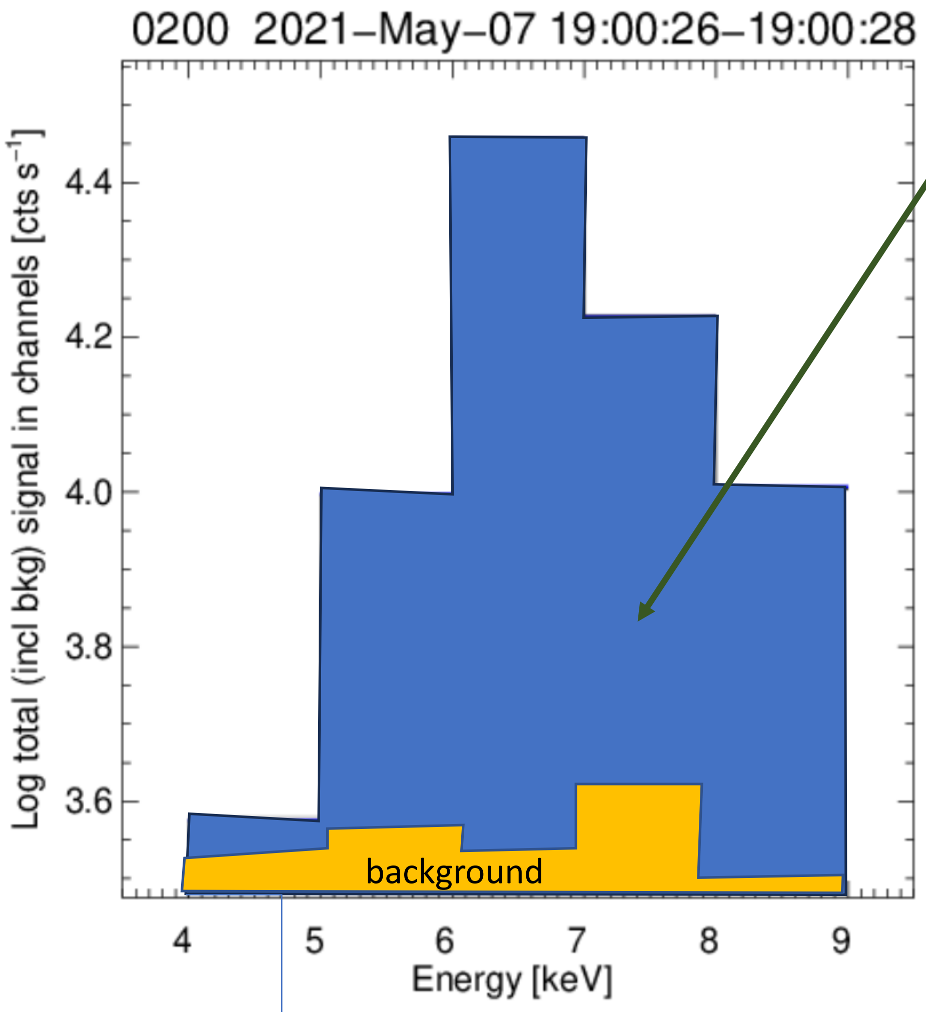






2614 DGI (data gather intervals), duration 20 s low count rates → 1 s closer to maximum

TEMIRA: temperature & iron abundance determination algorithm eliminating emission measure

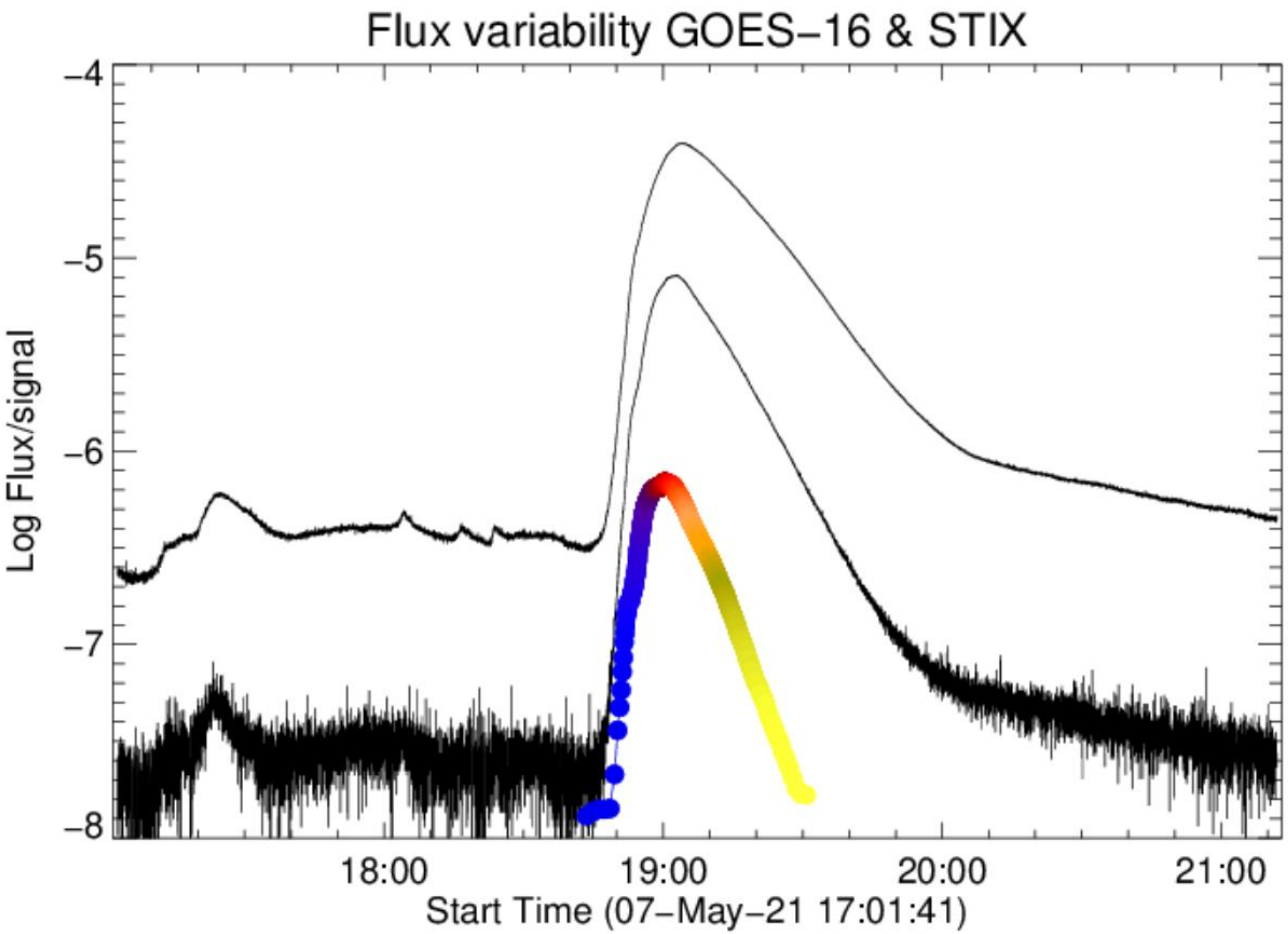


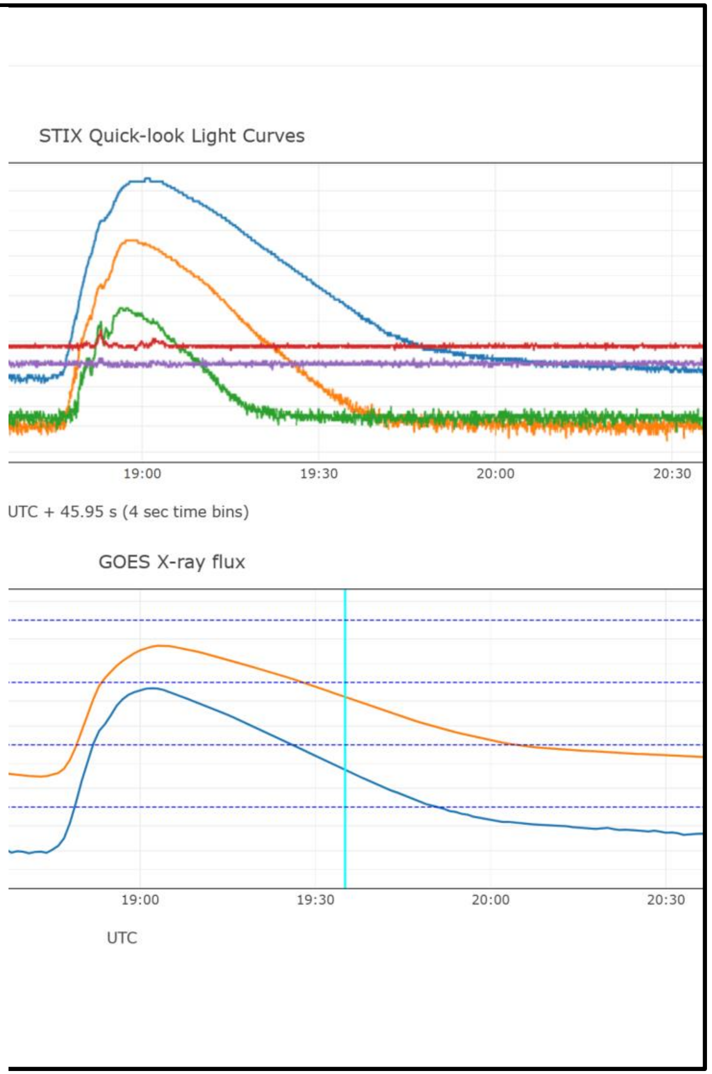
- Sum observed flux (above background) in the range **4 – 9 keV** i.e the thermal spectral region
- Divide this by CHIANTI predicted values (for such sum) for individual temperaures in the range 2 - 50 MK → gives corresponding individual EM's (intermediate running value)
- Use these individual EM to predict expected count rates in every of 5 channels: 4-5-6-7-8-9 keV
- Add background to predicted → calculated spectrum
- Compare observed to calculated spectra→ determine χ^2
- Repeat the procedure for another set of CHIANTI theory spectra, calculated with different $\mathbf{A_{Fe}}$ abundance
- Build T - $\mathbf{A_{Fe}}$ χ^2 surface & find the minimum
- Determine the minimum (optimum T, $\mathbf{A_{Fe}}$) and uncertainties from

  min (χ^2) +1 contour

The procedure is non-negative

The test performed for a well investigated flare of 7th May 2021 ~19:00 UT





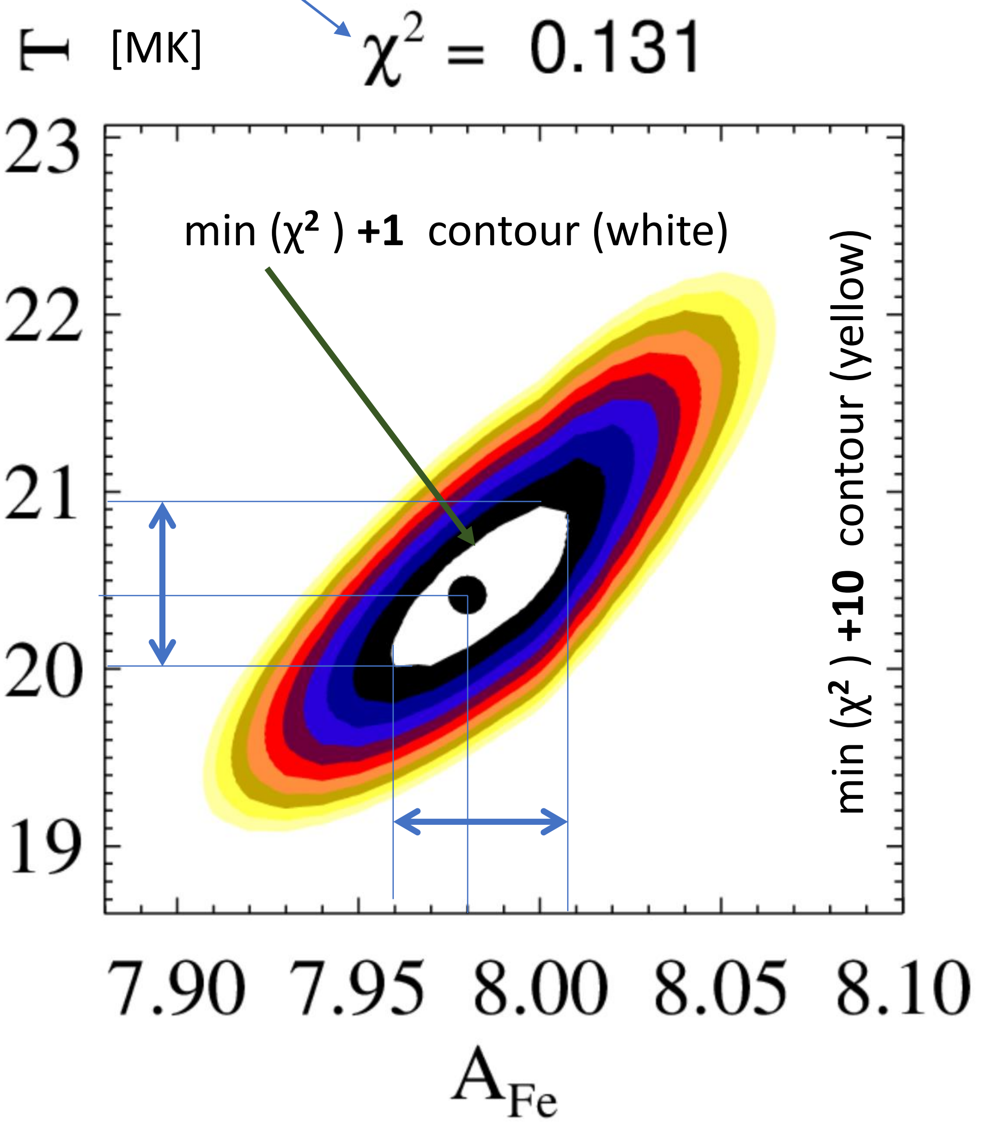
TEMIRA detailes

- Signal summed over **all 30 imaging detectors**
- **Background** in individual channels taken as time interpolated value (the analysis has been performed by KK using background files far from the Sun at low activity)
- Consecutive time intervals for processing selected periods to have at least $\mathbf{10^5}$ cts of **solar signal above background** (can be adjusted according to external „wishes"). This mean the No. of counts is similar → similar quality of the fit
- Respective GOES-16 T & EM values calculated (for "exact time frames") using programs **outside** „GOES environment"
- **TEMIRA** changes T & $\mathbf{A_{Fe}}$ and (by eliminating EM) compares shapes only between observed & predicted

  (theory signal+ background) is compared to (full **observed)**

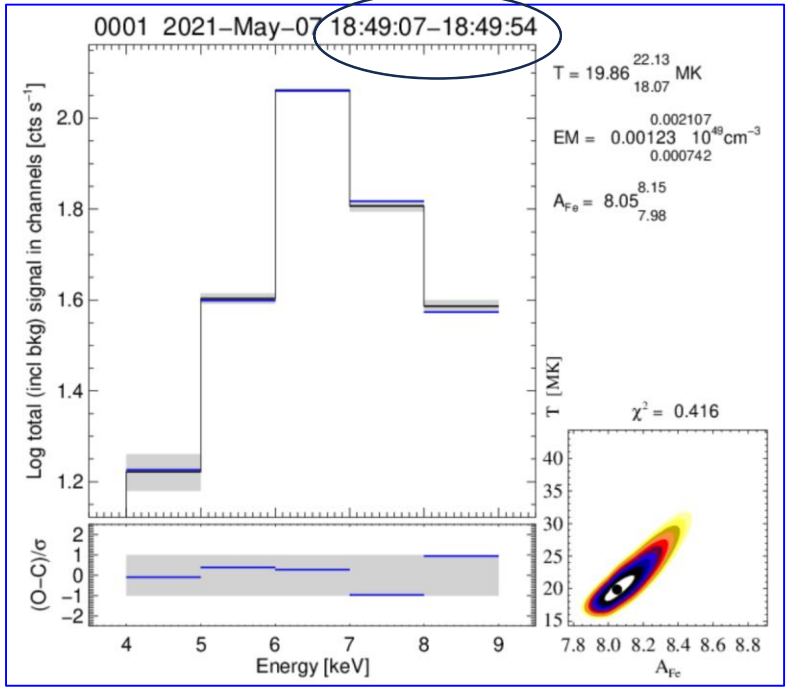
  in the five energy channels **4-5-6-7-8-9** keV
- Thus we calculate normalized optimum $\boldsymbol{\chi^2}$ surface in a classical way
- Position of minimum→ T & $\mathbf{A_{Fe}}$
- Uncertainties automatically provided for T & $\mathbf{A_{Fe}}$
- EM values & their combined uncertainties are obtained from **total flux in 4 -9 keV range (lot of counts)** and the optimum T & $\mathbf{A_{Fe}}$ with respective uncertainty limits

For time frame (200 round numer) as an example



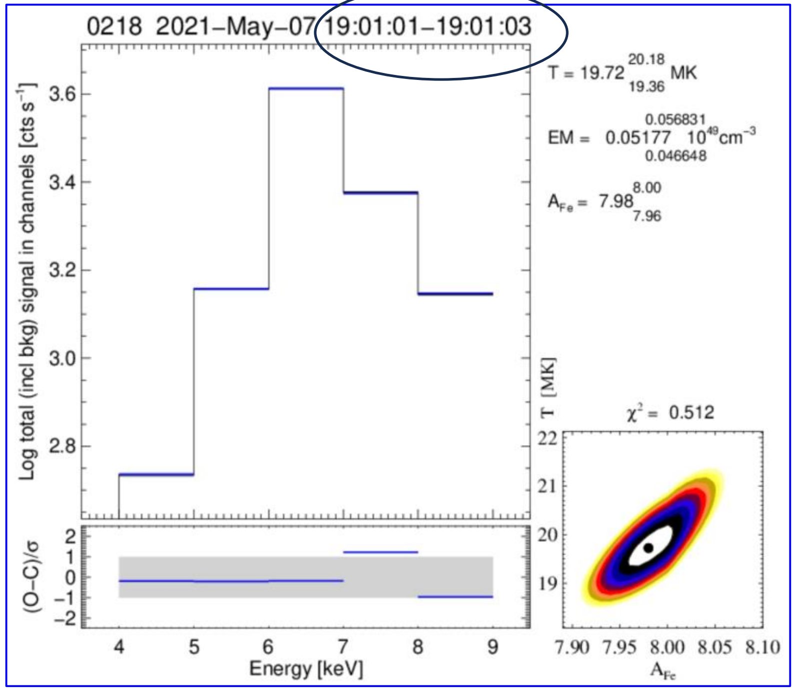
Some examples for time frames along flare evolution (black=observed, blue=best_fitted)

~1 min



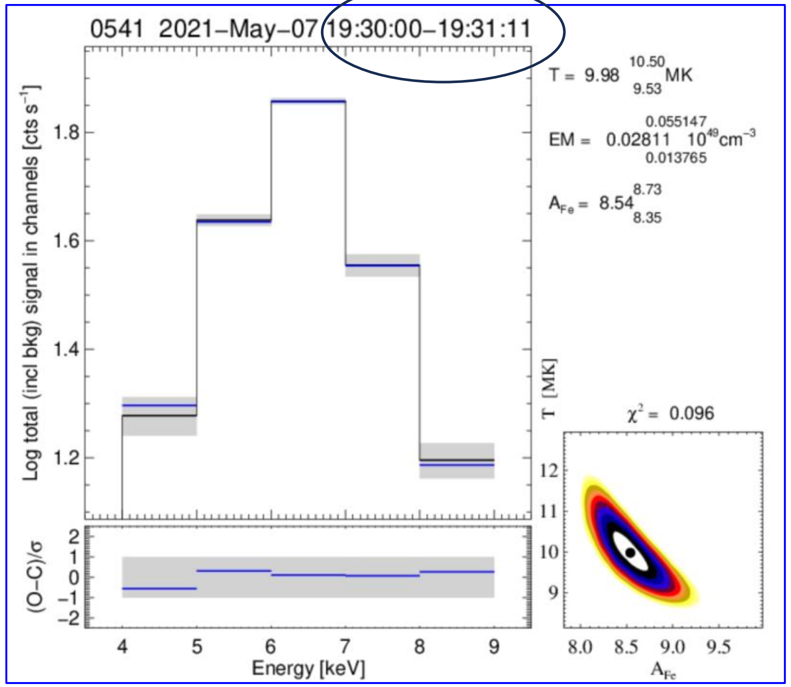
Early rise

~2 s



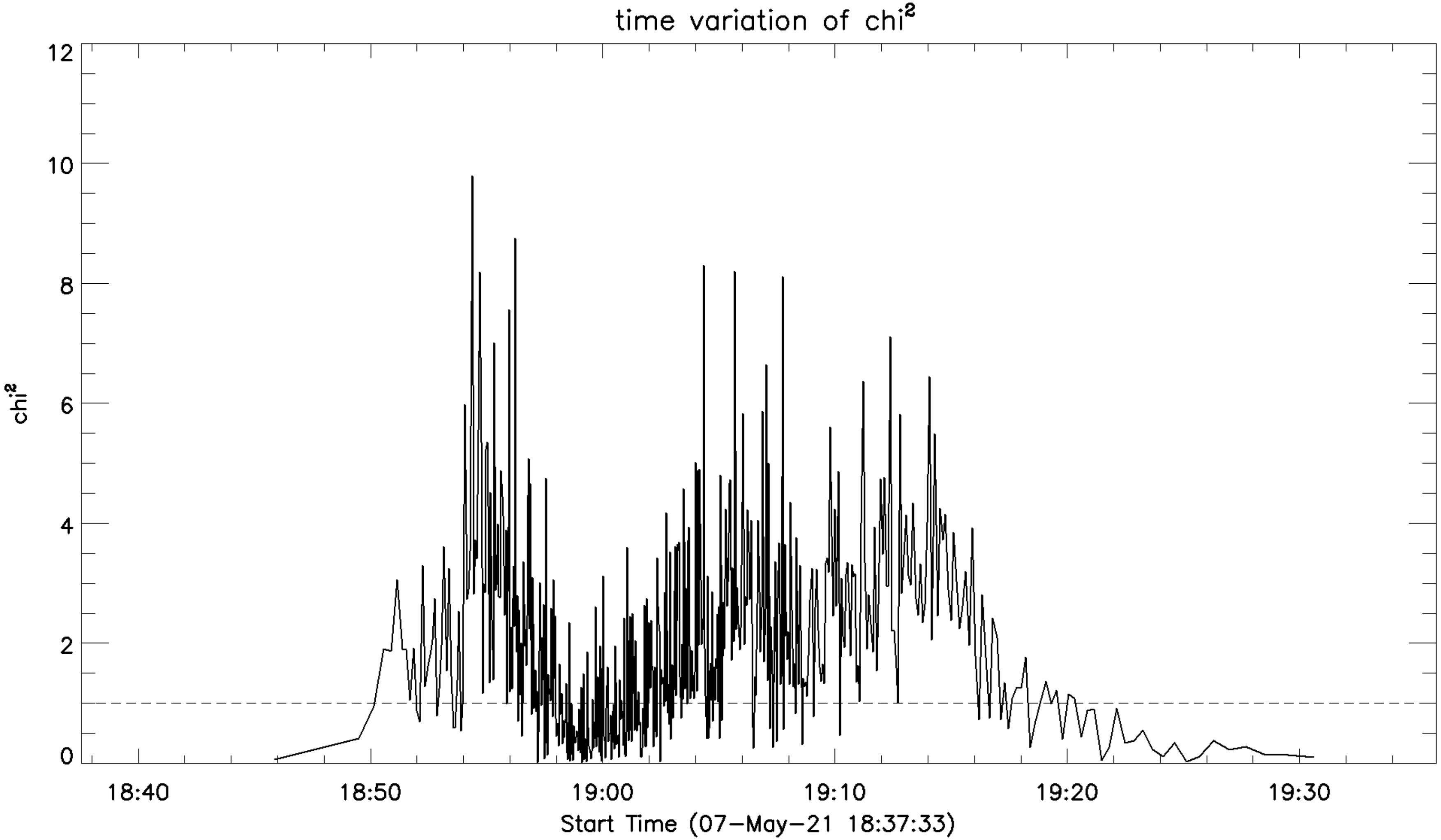
At flare maximum

~1 min

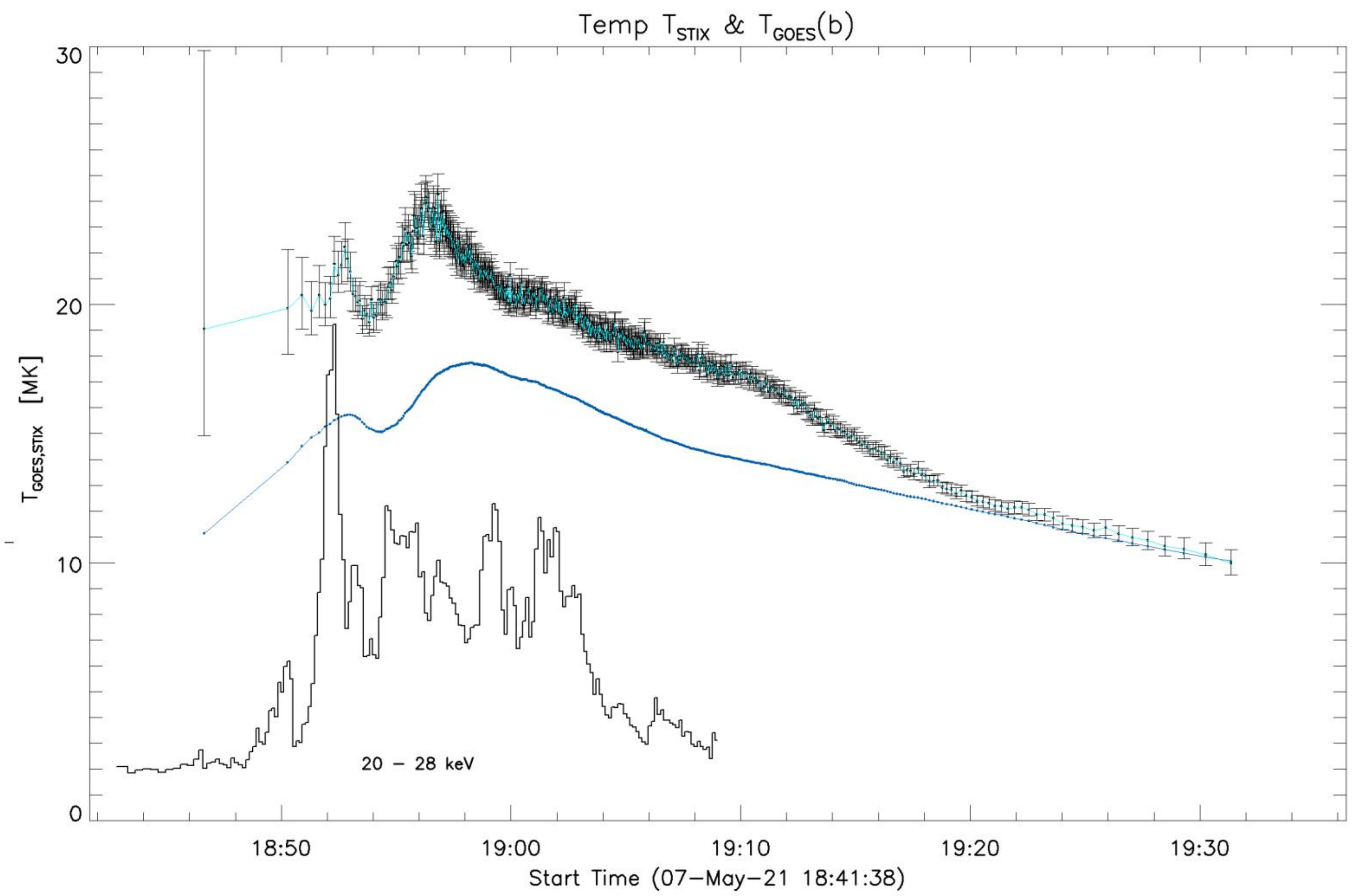


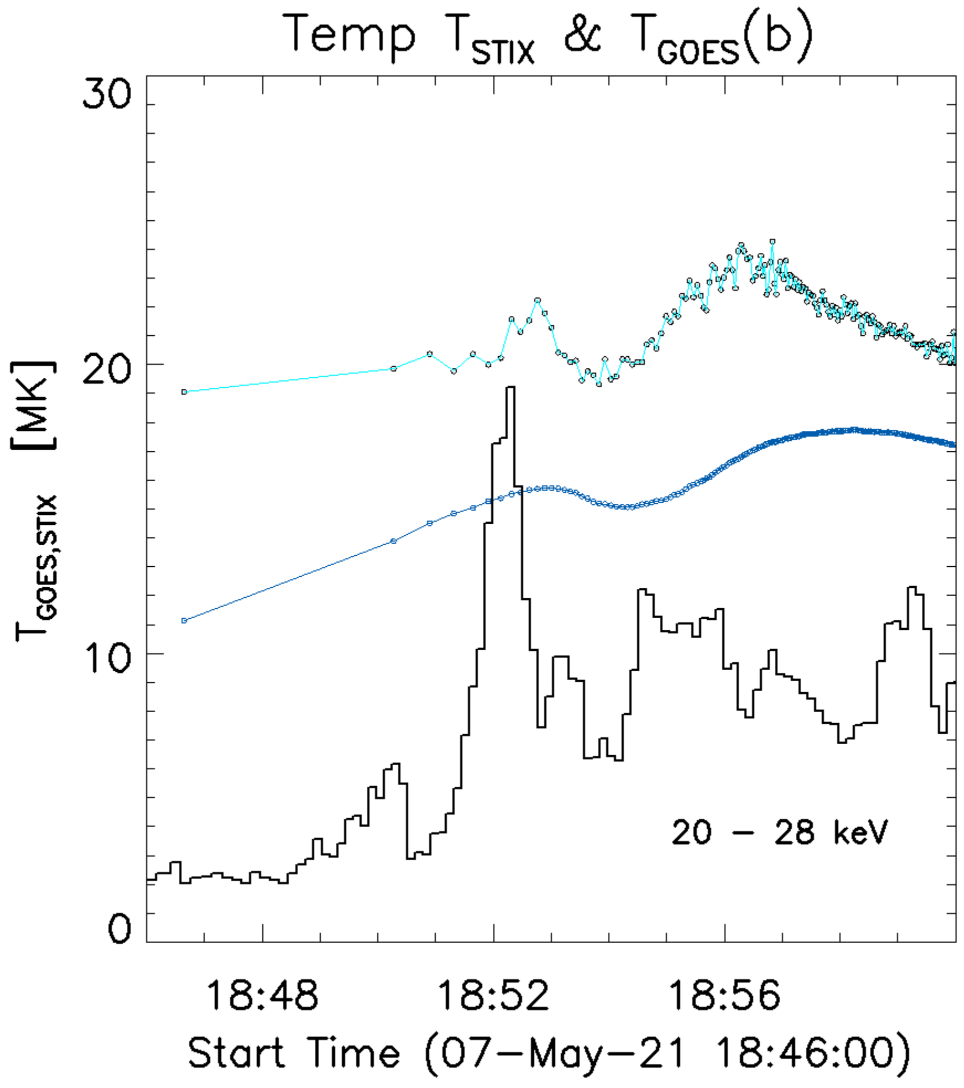
Late decay

Fit results to spectra at different phases as characterised by χ^2

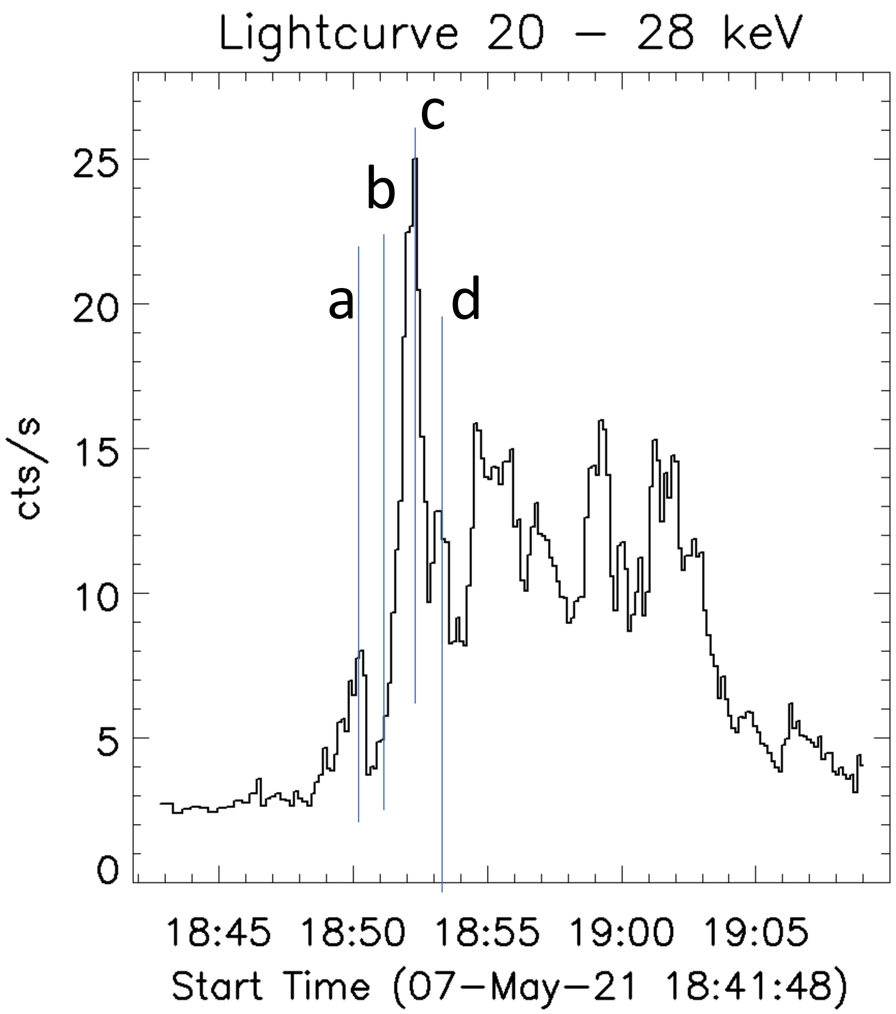


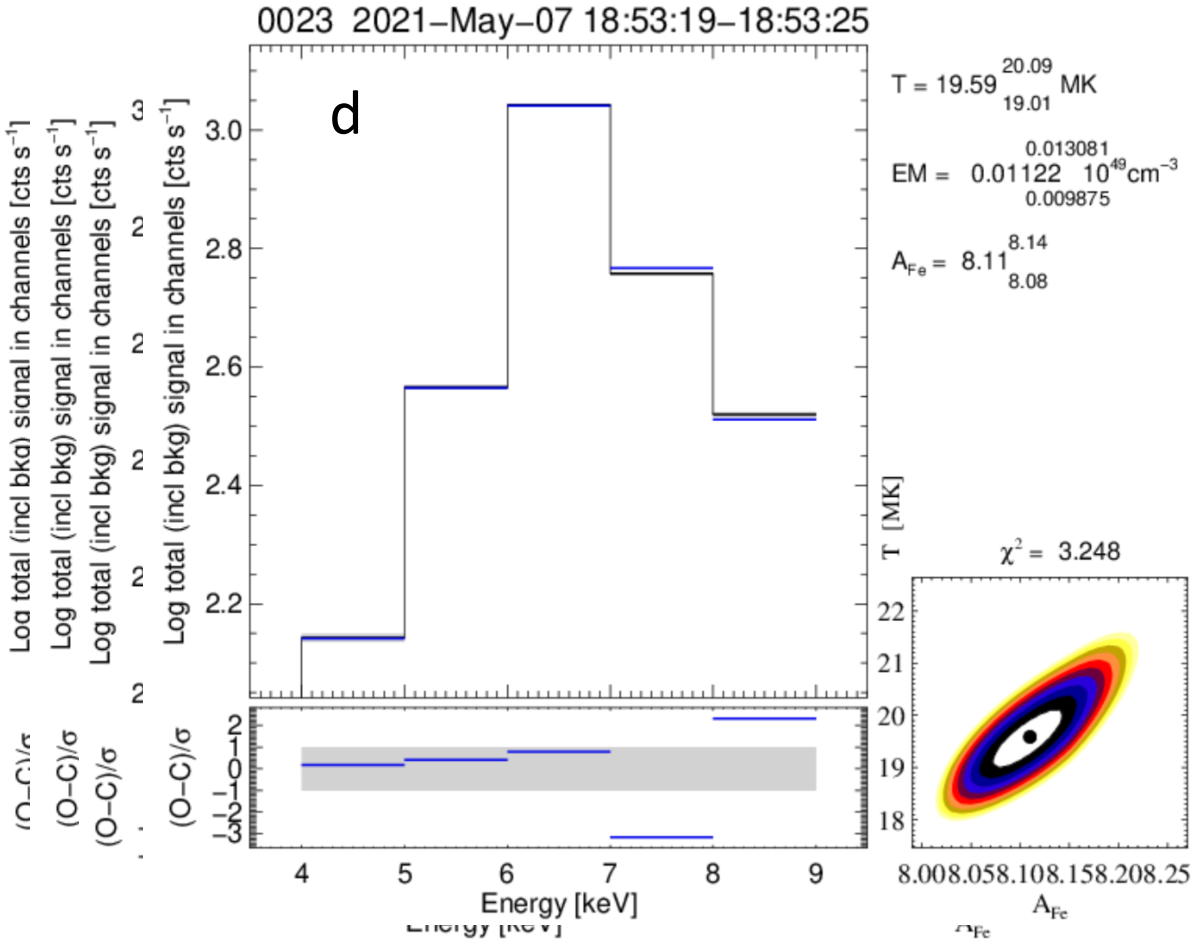
Time behaviour of T as determined using TEMIRA



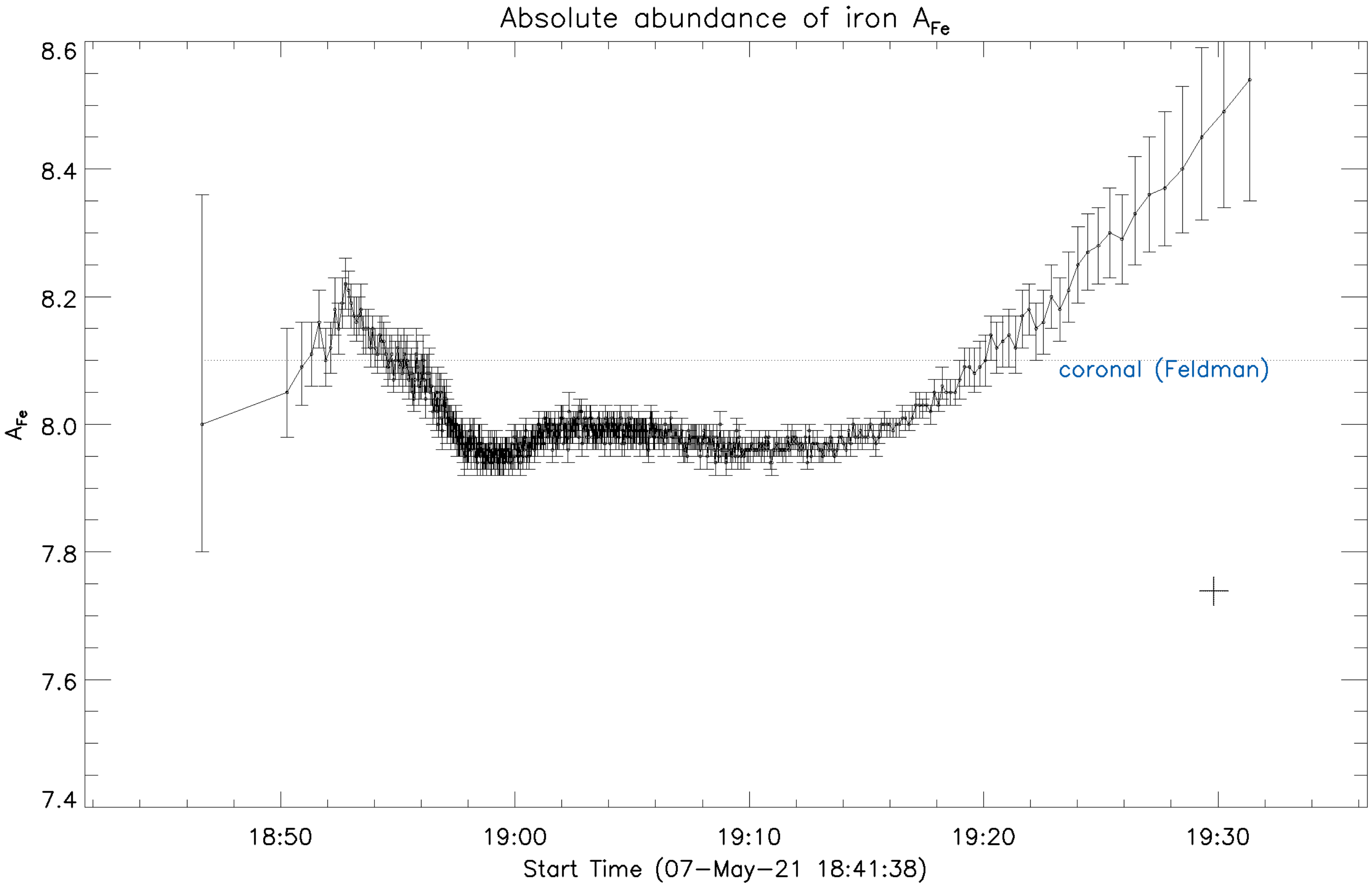


At a higher time resolution





Time behaviour of A_{Fe} as determined using TEMIRA



How STIX values of A_{Fe} compare with Chandrayan-2 XSM (DE analysis by Anna Kępa)

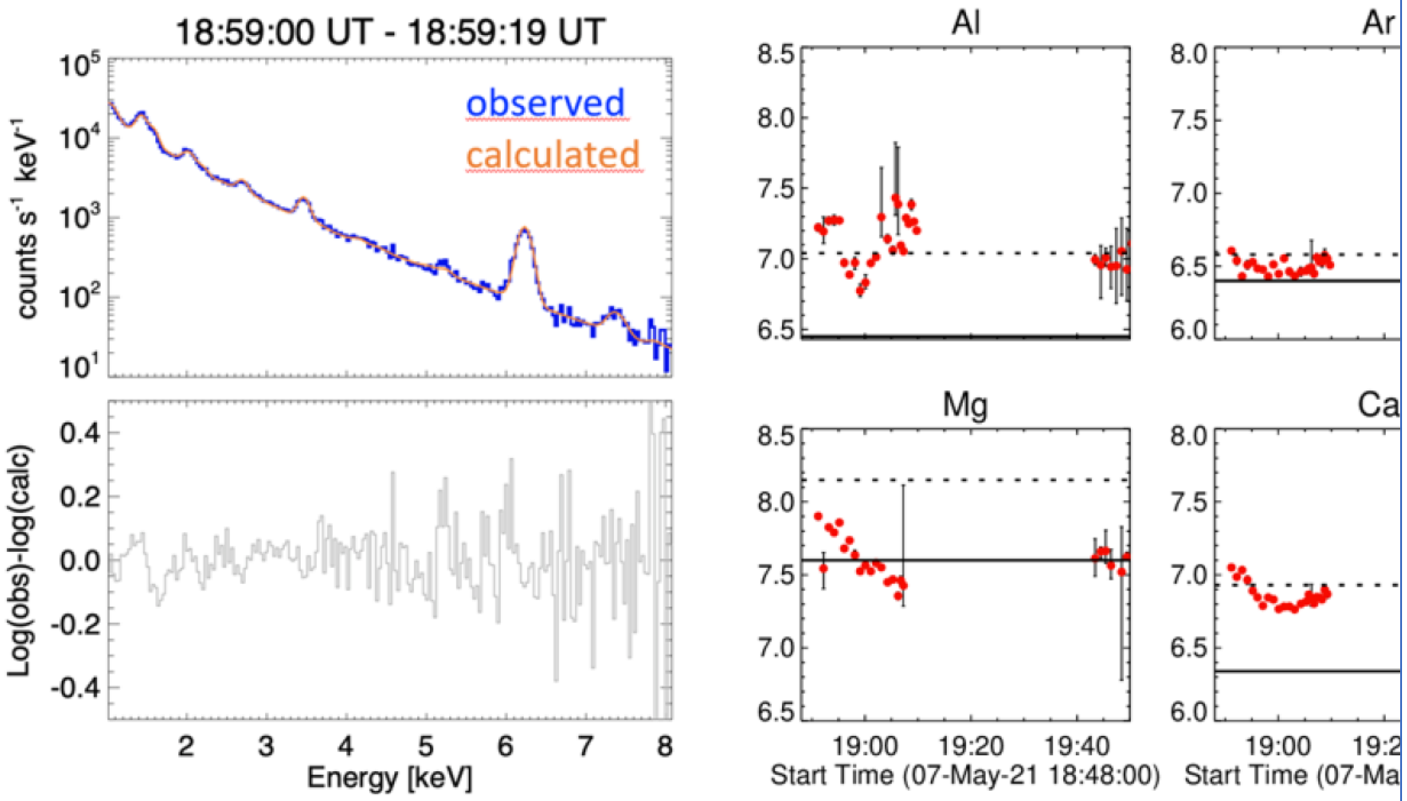
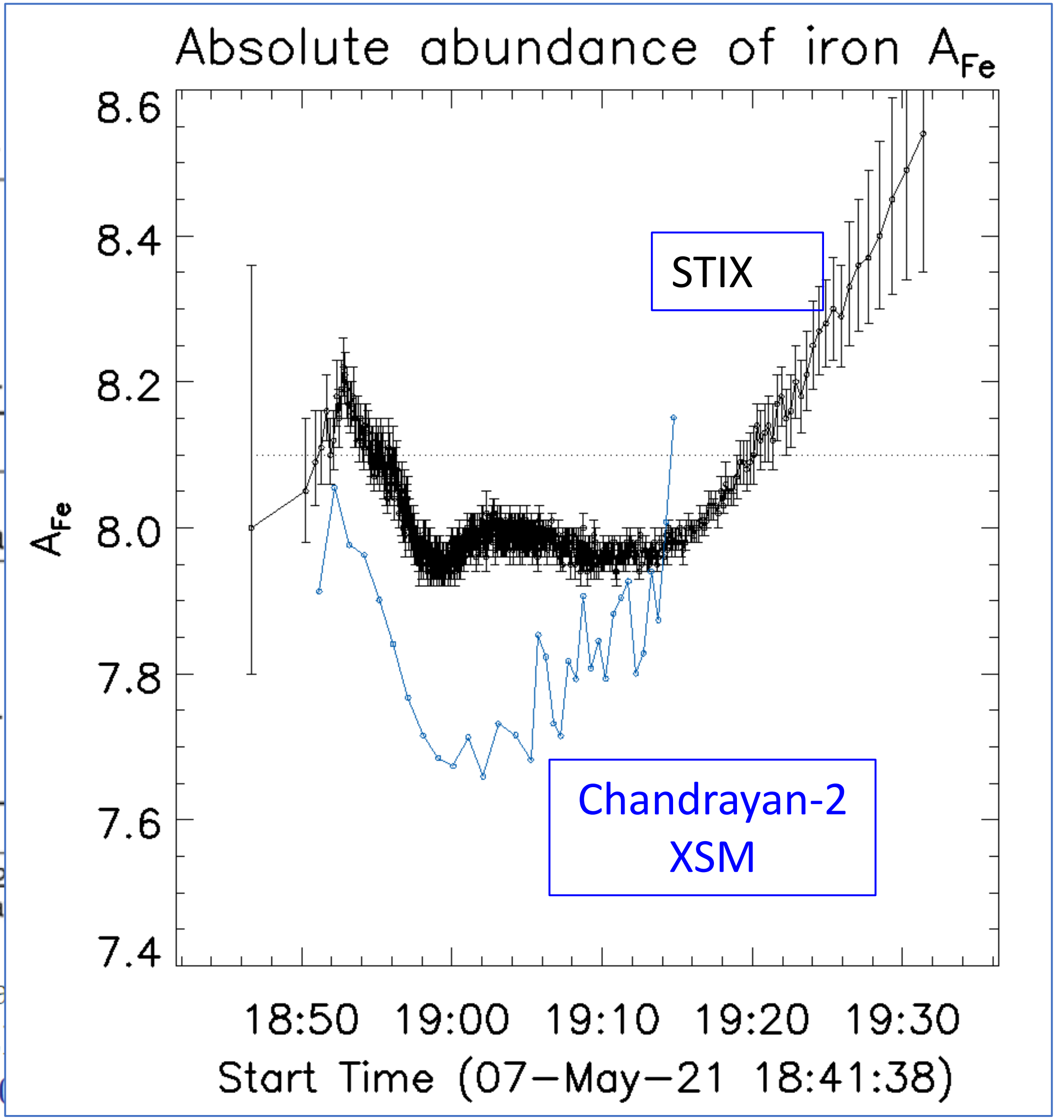
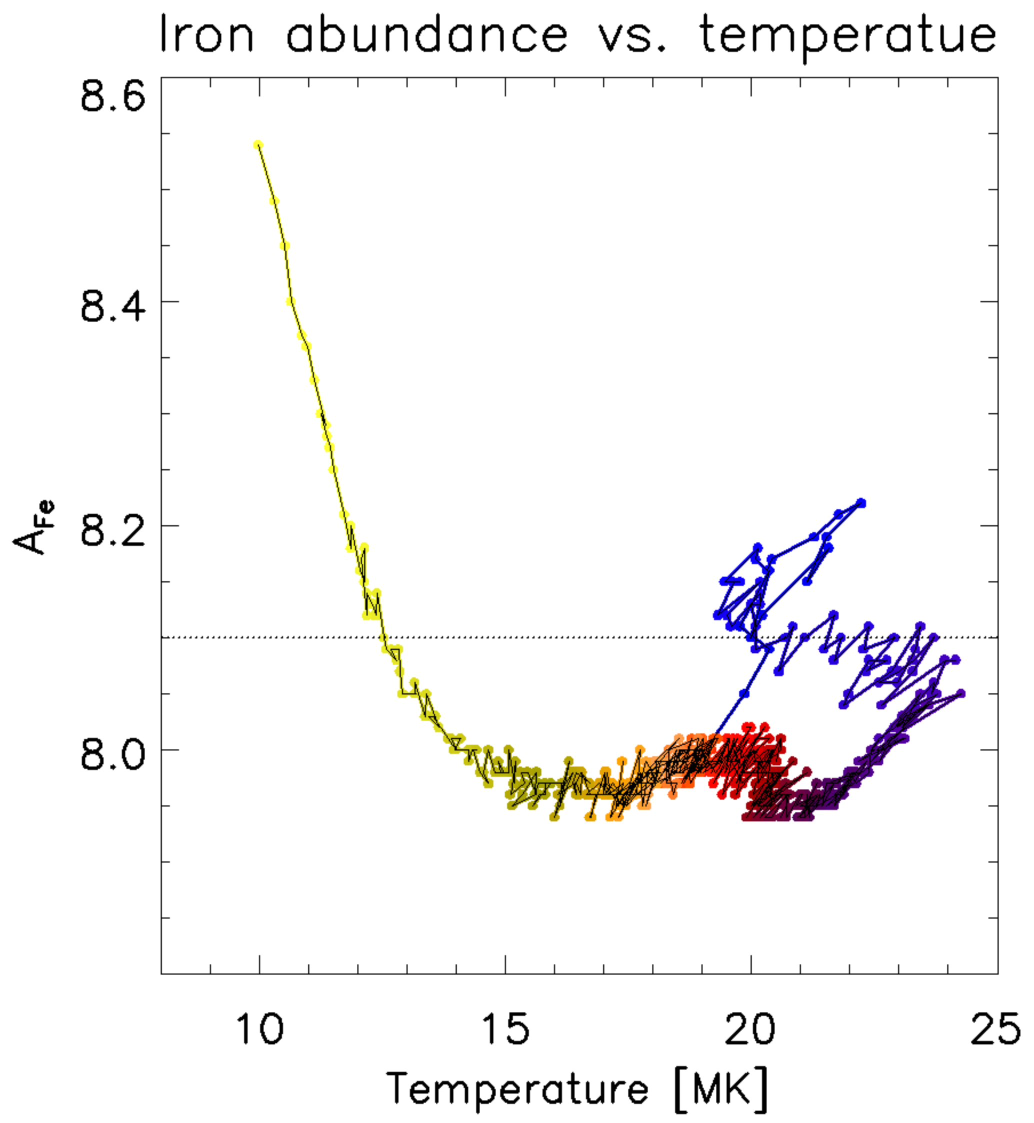
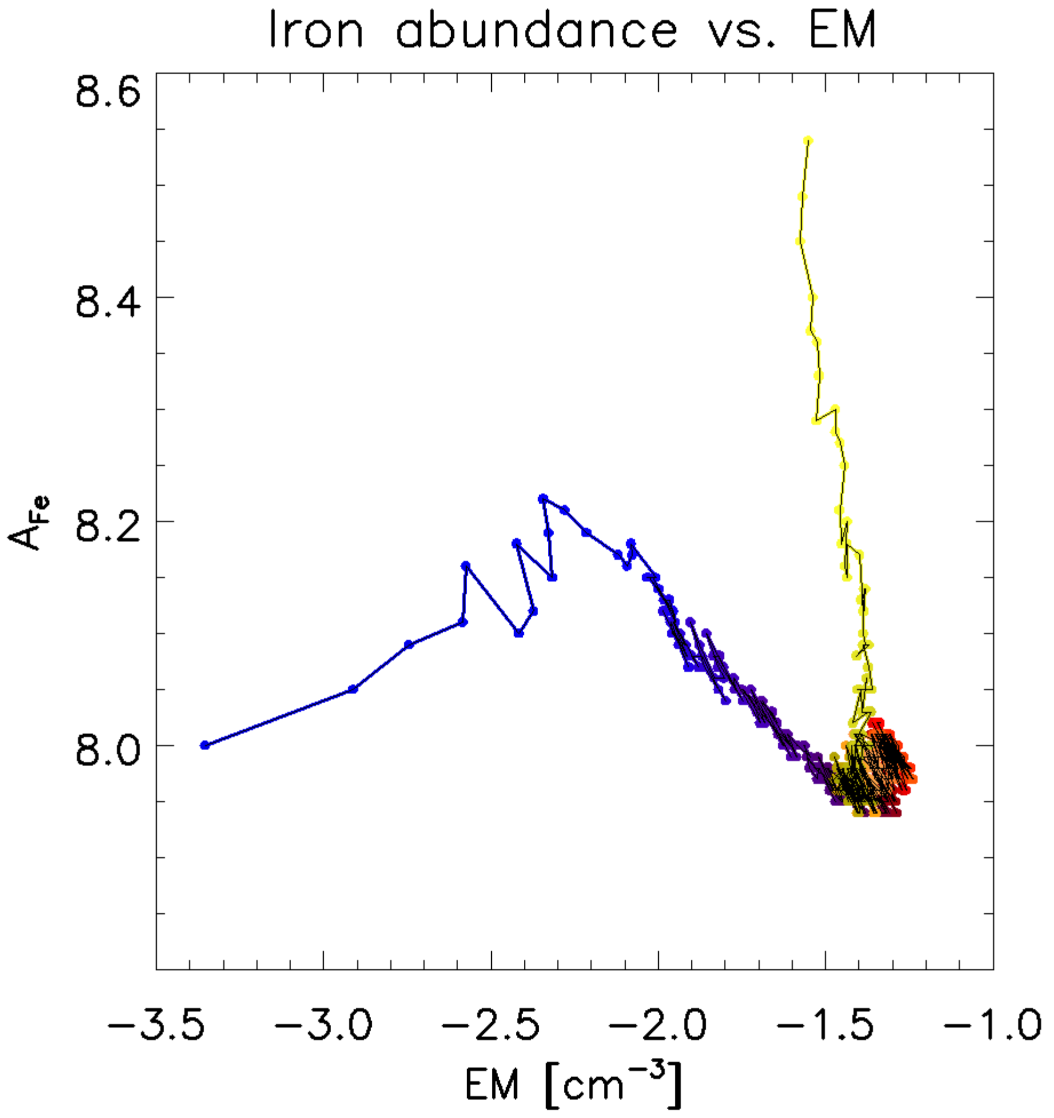


Figure 2. The observed (blue) and fitted (red) spectra taken close to ma
(below) and temporal variation of derived elemental abundances during t
lines represent coronal (Feldman 1992) and photospheric (Asplund et al. 2



Relation of A_{Fe} to T and EM





Overall

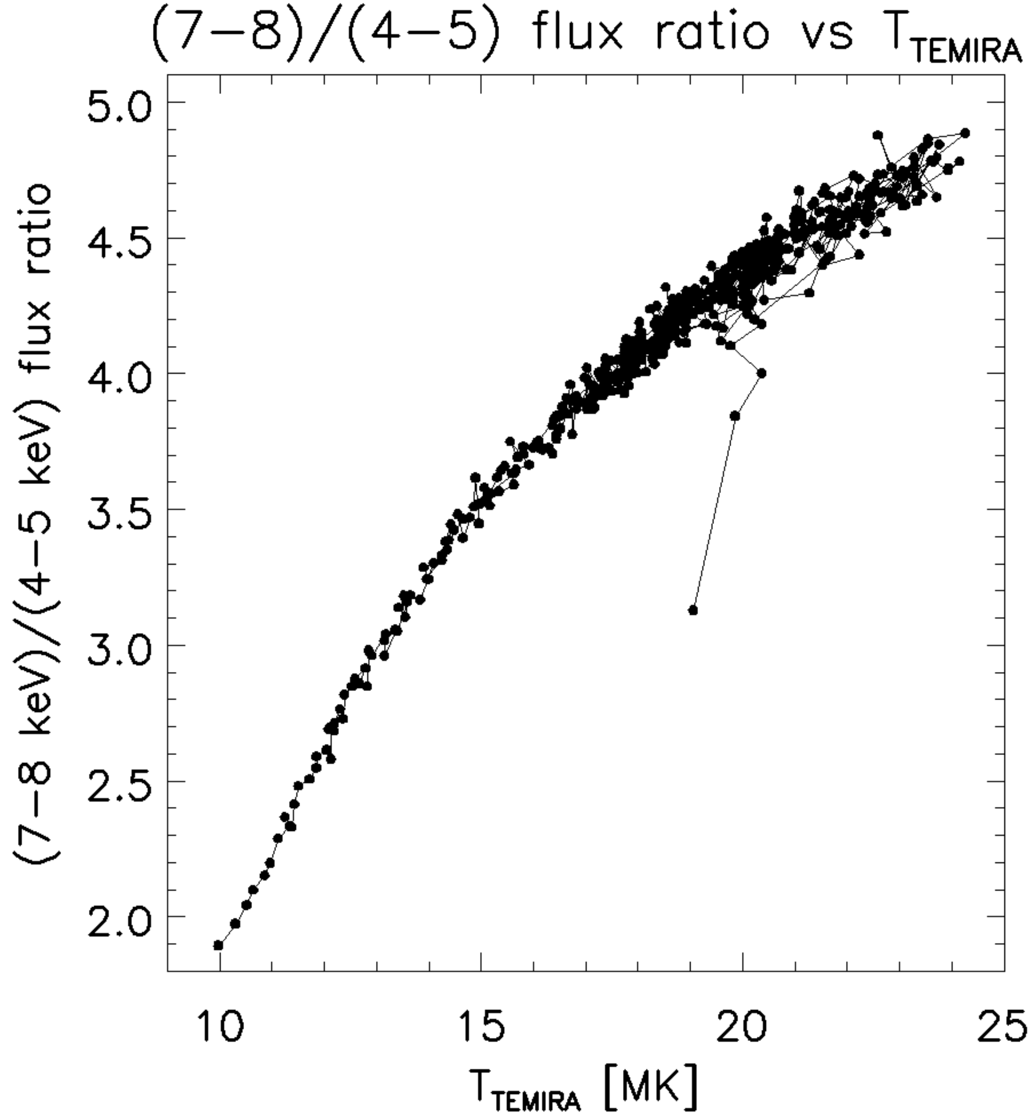
- Excellent fits (low **χ^2**) when appropriate background applied
- Reasonably quick computation time (1s per frame)
- T and $\mathbf{A_{Fe}}$ grid spacing of 0.001 dex

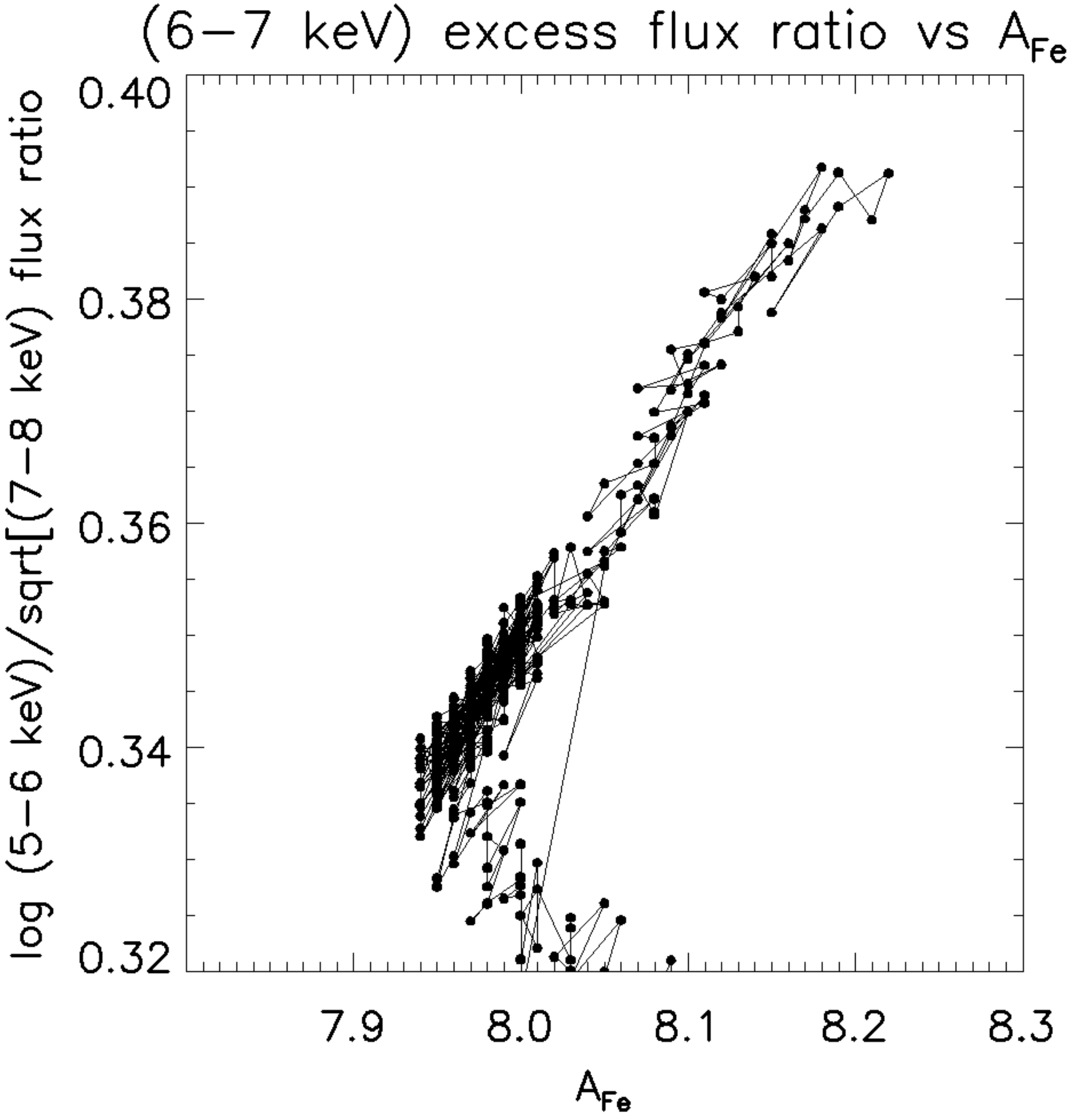
The most important

- **„New STIX Team” DRM 1054 x 1054** matrix works
- CHIANTI is capable of exact fit to the spectra when one-T approximation is accurate (near flare maximum), so the thermal CHIANTI emissivities with the new STIX DRM are ready to be used for interpretation of **thermal** flaring plasma component

Possible simple&quick T & A_{Fe} proxies

(might be used to speed-up TEMIRA)





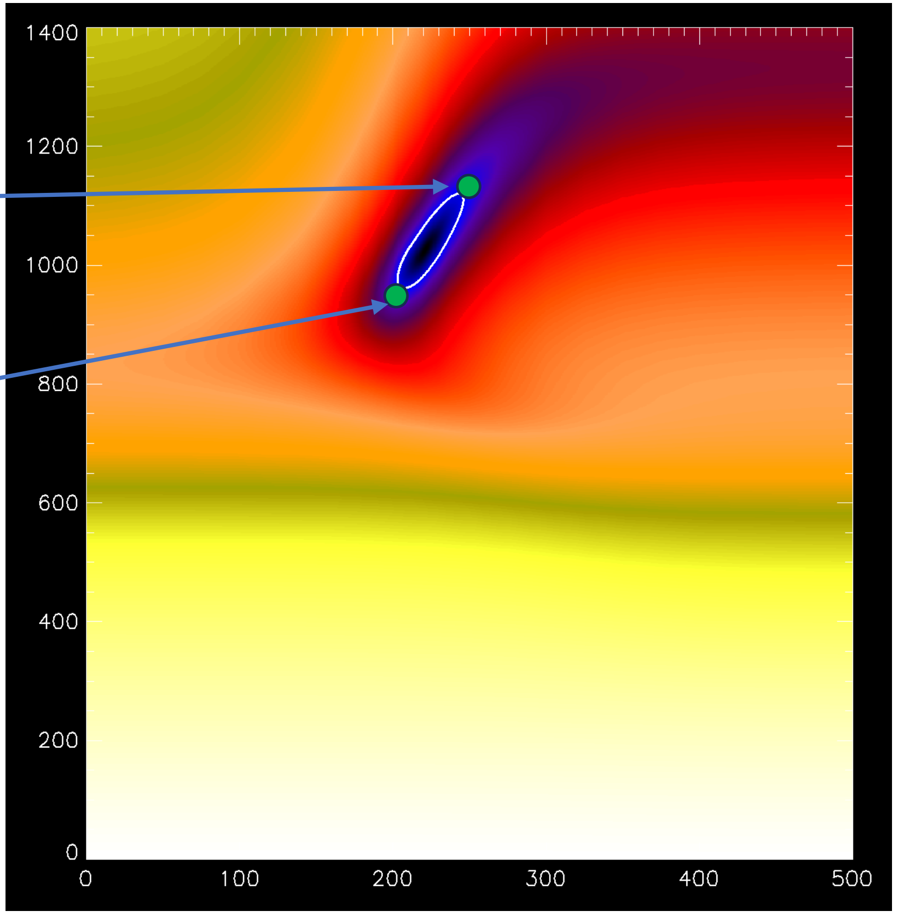
Future work:

- Prepare TEMIRA publication based on 7 May 2021 flare analysis
- ~700 flares are identified for TEMIRA analysis (these for which appropriate pixel data are available from STIX repository)
- Determine characteristic pattern(s) of A_{Fe} variation in flares
- Calibrate the (10-15)/(4-10) ratio against T_{TEMIRA} → T & EM plots
- It may be possible to determine A_{Fe} for individual flaring kernels from MARLIN images (to be discussed) or possibly even create maps of A_{Fe}

Thank you for attention

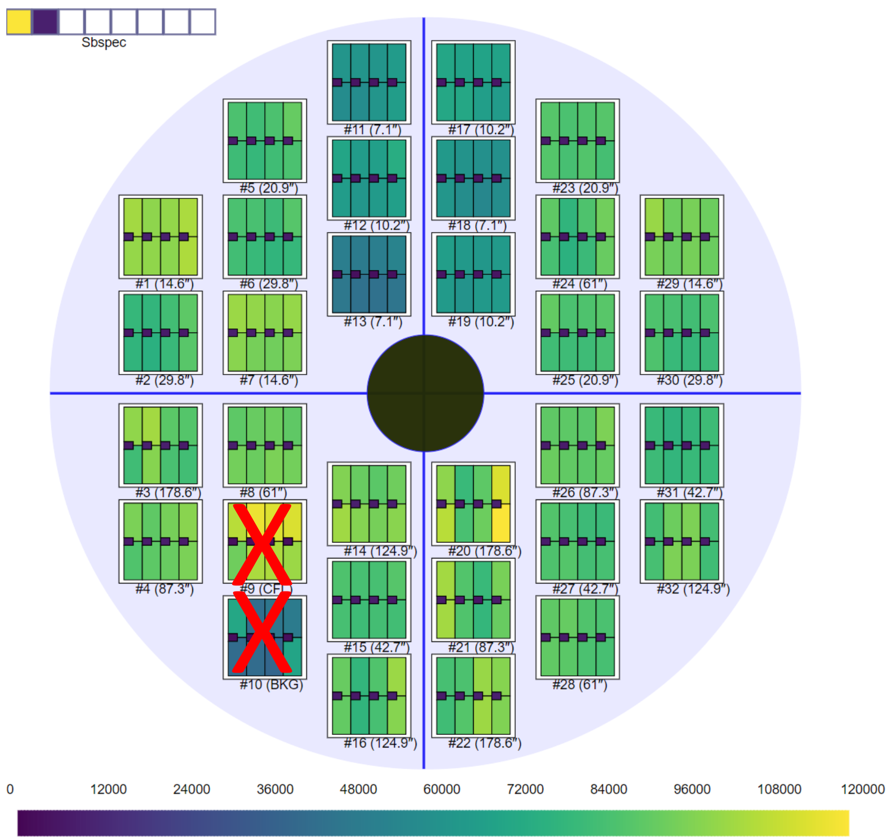
EM determination and its uncertainties is more complicated

- EM derived dependes on both T & A_{Fe} so
- $EM_{lower\ limit} = EM_i = (F_i - F_b)/F_5(T) \leftarrow$ upper limit T & A_{Fe}
- $EM_{upper\ limit} = EM_i = (F_i - F_b)/F_5(T) \leftarrow$ lower limit T & A_{Fe}



Combining signal from 30 imaging detectors

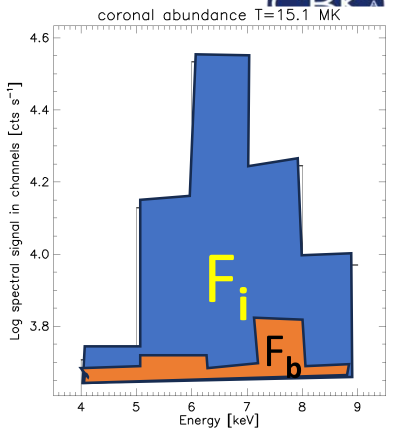
(use of modified `stx_construct_pixel_data`)



Steps in processing

- Combine signal from all (12) subpixels of every detector
- Add signal from 30 imaging detectors (these behind slits)
- Correct for instrumental effects (live time etc in standard processing pipeline)

New philosophy of fitting step by step individual time step cd



1. Integrate the flux in 5 low-E channels (4-5-6-7-8-9 keV): F_i
2. Assume running T in the range 2-100 MK
3. Calculate corresponding 5-channel contribution functions at T $F_5(T)$ for selected iron abundance A_{Fe}
4. Determine running $EM_i=(F_i - F_b)/F_5(T)$
5. Calculate spectrum in all 5 channels using EM_i and respective theory
6. Add background to every channel
7. Calculate normalized χ^2 in a standard way
8. Repeat steps 2 ÷ 7 for next temperature
9. Repeat „everything” for another abundance A_{Fe}

for 1401 value of T from 2 -100 MK
Every 0.001 dex

for 501 value of A_{Fe} from 6 - 11
Every 0.001 dex