Progress on SMM BCS spectra Analysis
Evolution of High resolution spectra for a number of impulsive flares

J. Sylwester, B. Sylwester,
A. Kepa, Z. Szaforz, K. J.H. Phillips

Why returning to 30+ old measurements

- „Golden age” for solar X-ray spectroscopy
- VERY HIGH spectral resolution (instrumental width<<thermal or turbulent width)
- High-Z spectra Ca (XIX) & Fe(XXV)
  - →strong satellite lines present
  - → DE satellites provide “plasma temperature”- but this might be just “equivalent” of the temperature (population of the resonance to tail)
  - Innershel excitation/ionisation transitions
  - Ka lines seen (impact excitations? & fluorescence 99% of the photosphere from overlying strong coronal source)

Bent-Crystal Spectrometer
Solar Maximum Mission
1980-1989

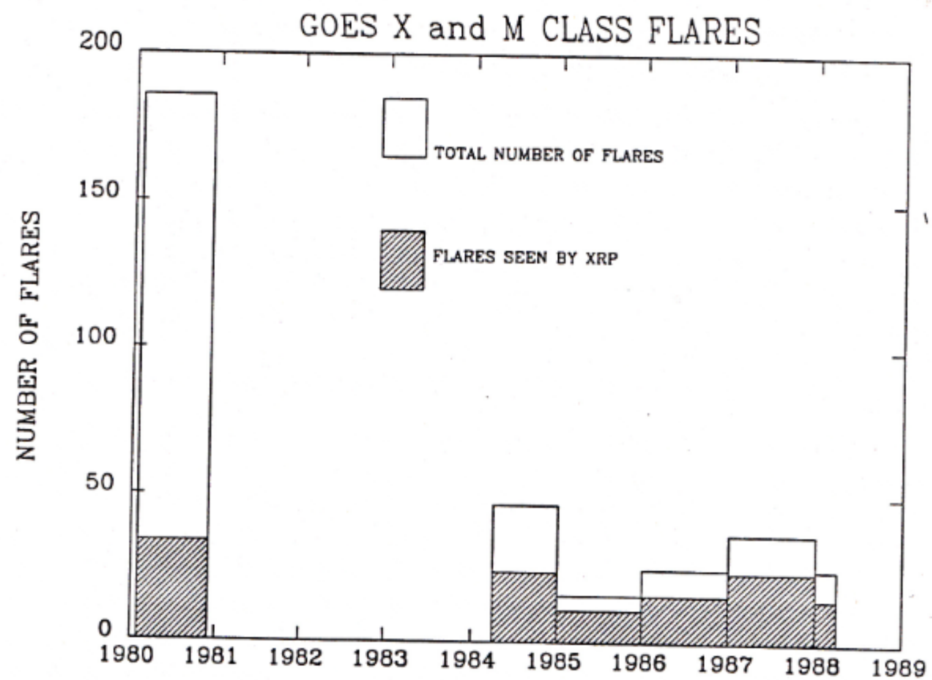


Figure 1-5. M- and X-level Flares observed by *SMM*.

Adventages of SBCS (SMM BCS)

- Extremely high sensitivity (Ca XIX -10 MK+ & Fe XXV 15 MK+ plasmas)
- Overlapping channels: indepednent detectors & electronics→ cross check possible
- The 2D collimator present if front 6 x 6 arcmin
- Sufficient DGI ~30 sec- may allow for non-equilibrium studies
- Preserved data set ~ 1000 flares x 200 spectra

Dis-adventages of SBCS

- Poor/non-existent instrument documentation (instrument paper not written- hand written pages available from Chris Rapley)
- Software missing in IDL to interpret spectra (VMS FORTRAN spectral fitting package SPCFIT rediscovered – Andrzej Fludra)
- Pointing of ROI areas yet un-discovered
- Catalogue of measurements is missing.

WHY to go back & investigate

- Unprecedent spectral resolution, time resolution & sensitivity (to be shown)
- Many lines due to different types of transitions observed “instantanousely” for heavy ions. Time to ionise these ions is expected to be comparable to DGI
- Continuum is “present” and not “contaminated” strongly by fluorescence in most of channels except the Fe XXVI

OUR revitalization project- subject to grant application?

- Recover the software to read & understand the measurements (based on Dominic Zarro routine to access the “bda” spectral files)
- Recover and use the HXRBS hard X-ray intensity profiles with 0.1s time resolution- not available for RHESSI
- Create a catalogue of ~ 1000 spectral events- all present on NASA SBCS data base (Zaneta & Ania)
- Create algorithm to „isolate” overlapping lines
- Provide the community with light-curves of selected line emissions due to resonance, DE, IE, II lines of ions of interest Fe XXVI-XIX-Ka

BCS characteristics

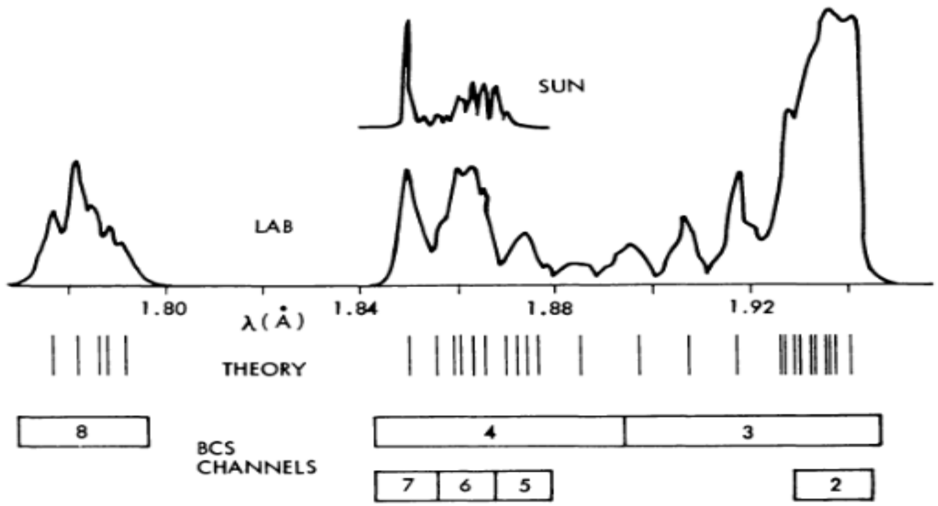


Fig. 7 Spectral coverage of the 7 short wavelength BCS channels. Actual spectra and theoretical line positions are shown schematically for comparison.

Table 1-1. BCS Characteristics

Channel	Ion Stage Number	Wavelength (Å)	Peak T_e (10^6 K)	Resolution $\lambda/\delta\lambda$
1	Ca XIX	3.165 – 3.231	35	3463
2*	Fe^{inner}_{shell}	1.928 – 1.945	2	11206
3	Fe^{inner}_{shell}	1.839 – 1.947	2	4075
4	Fe XXV	1.840 – 1.984	50	3967
5	Fe XXV	1.866 – 1.879	50	8937
6	Fe XXV	1.854 – 1.867	50	8937
7	Fe XXV	1.842 – 1.855	50	8911
8*	Fe XXVI	1.769 – 1.796	60	7005

* Channel has data for 1980 only

In-flight calibration of detectors

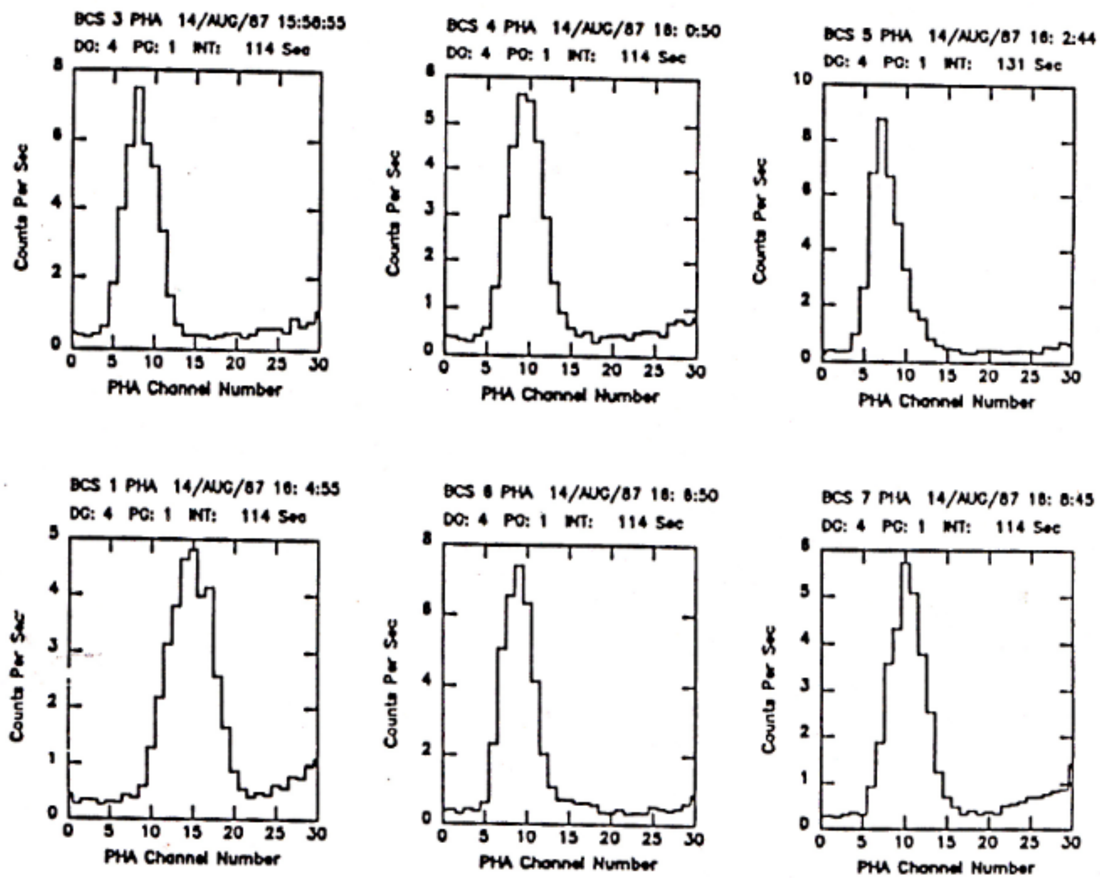


Figure 2-16. Sample BCS PHA calibration data obtained in channels 1 and 3 to 7 using a $^{+55}$Fe radioactive source.

Time degradation

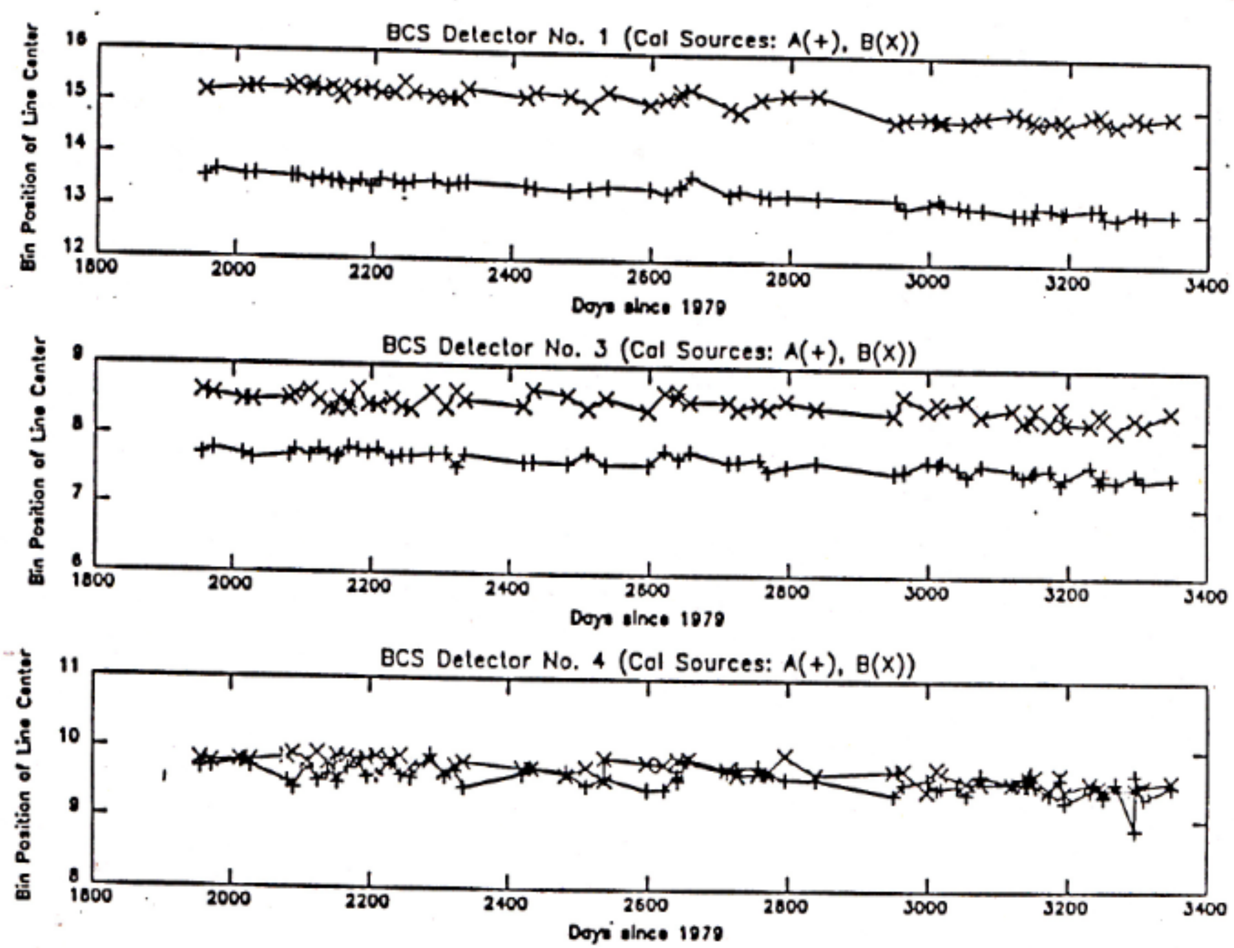


Figure 2-17. Time history of the BCS PHA calibration data. Channels 1, 3 and 4 are displayed. These data indicate the stability of the detector gains as a function of time.

Problems

- Dispersion never account for non-linearity of crystal reflections
- For 1984-1989 periods some channels are missing
- CHIANTI DW not of “sufficient accuracy” to accommodate theory spectra- not all lines present etc. Old spectral data files still present

c:\ssw\gen\data\spectra*.*

Nazwa	Roz.	Wielkość	Czas
[..]		<DIR>	2013-03-28 09:26
cabal1	dat	710	1994-10-05 03:00
casec4	dat	11 880	1993-10-05 03:00
f26sec4	dat	6 442	1993-10-07 03:00
febal1	dat	1 591	1993-10-08 04:08
febal2	dat	4 552	1998-01-05 14:20
fesec4	dat	17 784	1993-10-06 03:00
mewe_cosmic	genx	399 472	1993-02-25 01:00
mewe_solar	genx	399 492	1993-02-26 01:00
subal1	dat	1 025	1993-09-01 03:00
susec4	dat	8 798	1994-01-13 01:00
susec5	dat	14 588	1994-03-24 01:00
susec6	dat	24 175	1995-05-02 03:00
uv_xsections	dat	3 362	2000-03-31 11:31

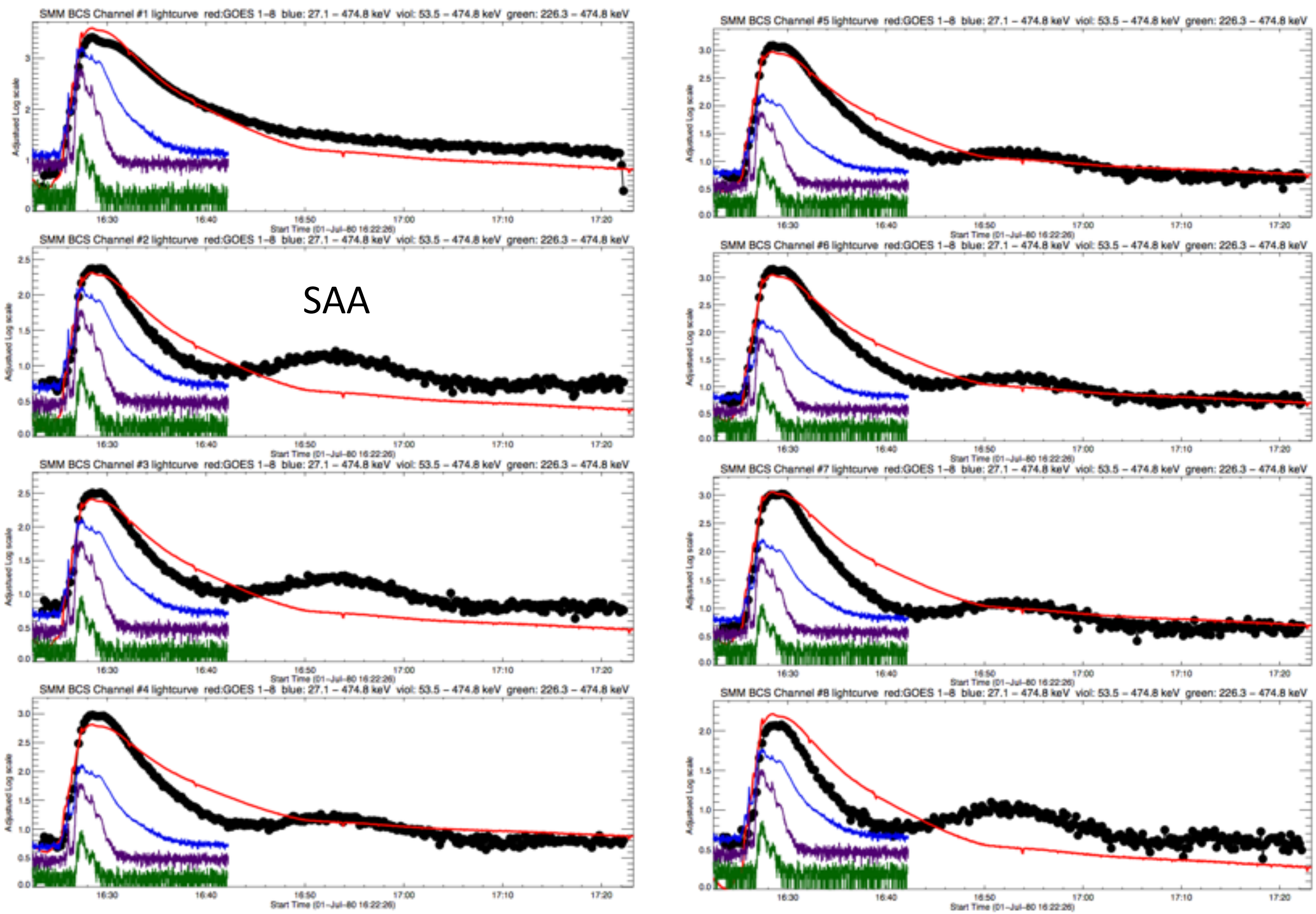
Problems II

- Hand-written unchecked effective areas (now recalculated by Zaneta ☺)
- Peak Collimator transmission known from one remark 33%- we can use the ratio of Ca channel/ GOES 1-8 A to „place the flare within” the FOV
- No data for flare sources moving transversally across the FOV of the collimator (no RHESSI)- availability, HXIS data were not checked yet!!
- Missing documentation!!!

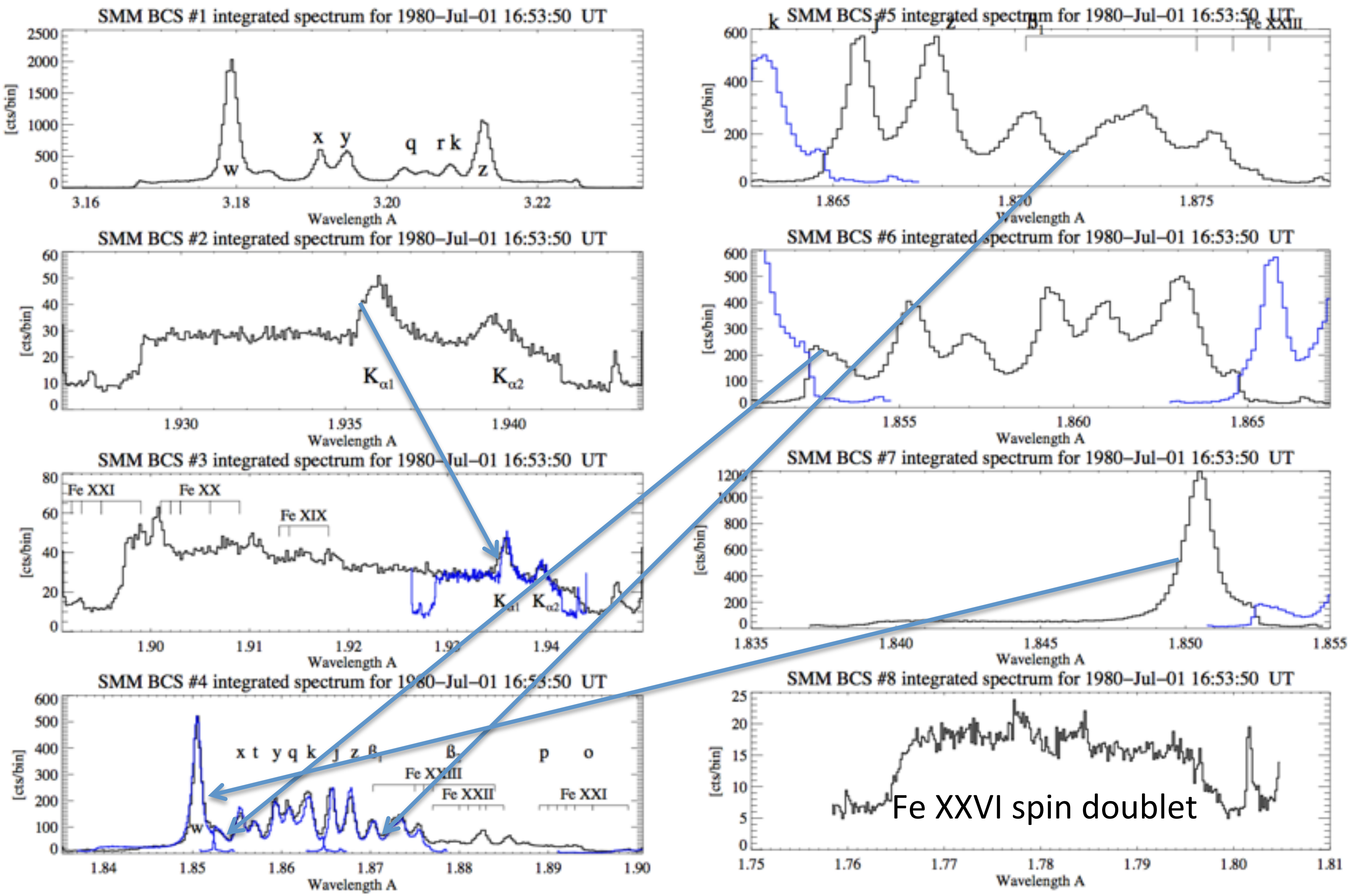
However the data are “fantastic”

- We will soon see them
- We have the team of experts who learnt the BCS (RESIK and Yohkoh BCS)
- There are new Crystal codes available to re-calculate the Rc and effective areas done!
- New atomic data are present (f.i. Kanti Aggarwal for He-like ions)
- The team is enthusiastic to work on this “reincarnation” project:
  - Anna Kepa & Zaneta Szaforz

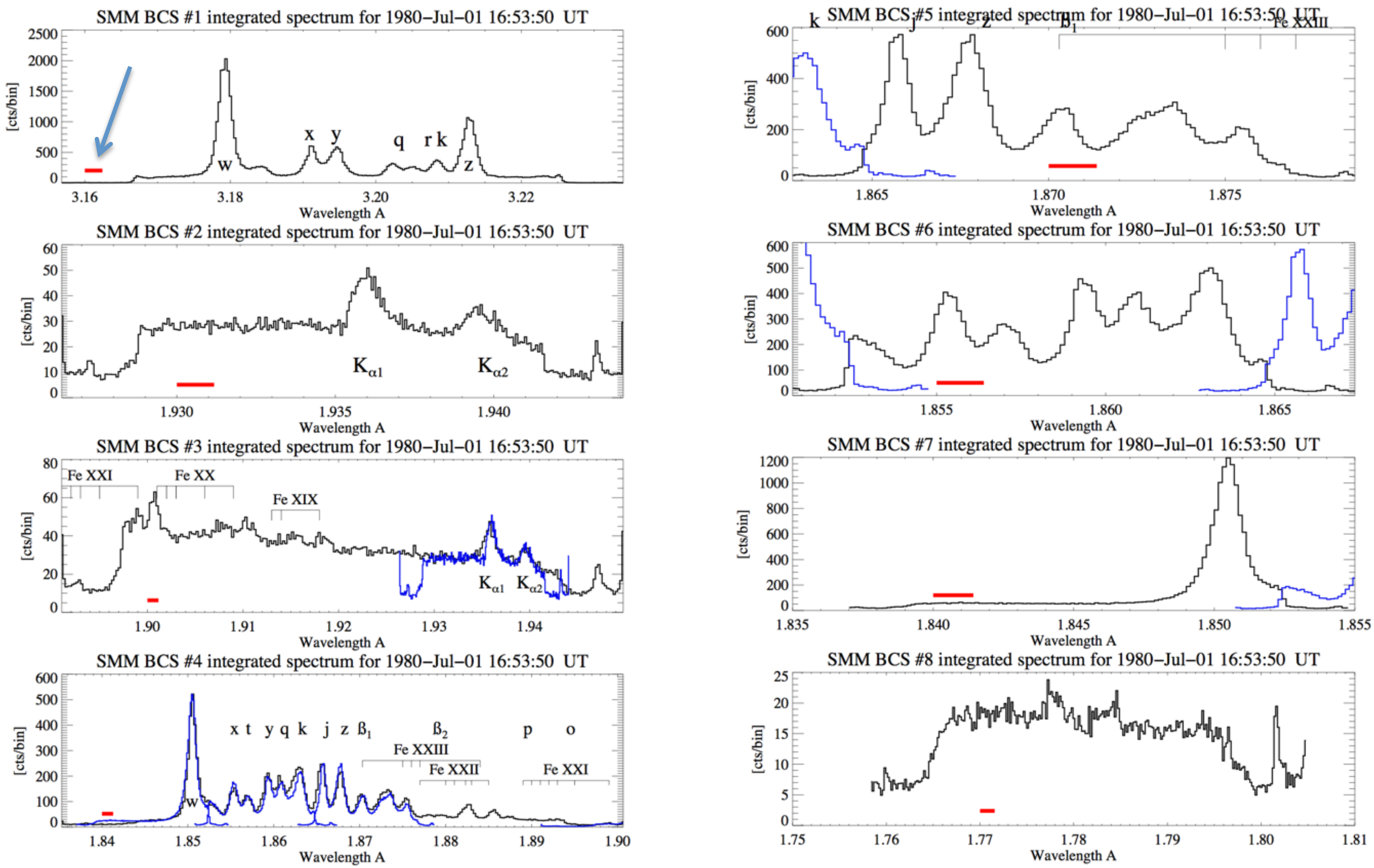
The observations: example flare SOL1980-Jul-01 impulsive event all 8 SBCS channels



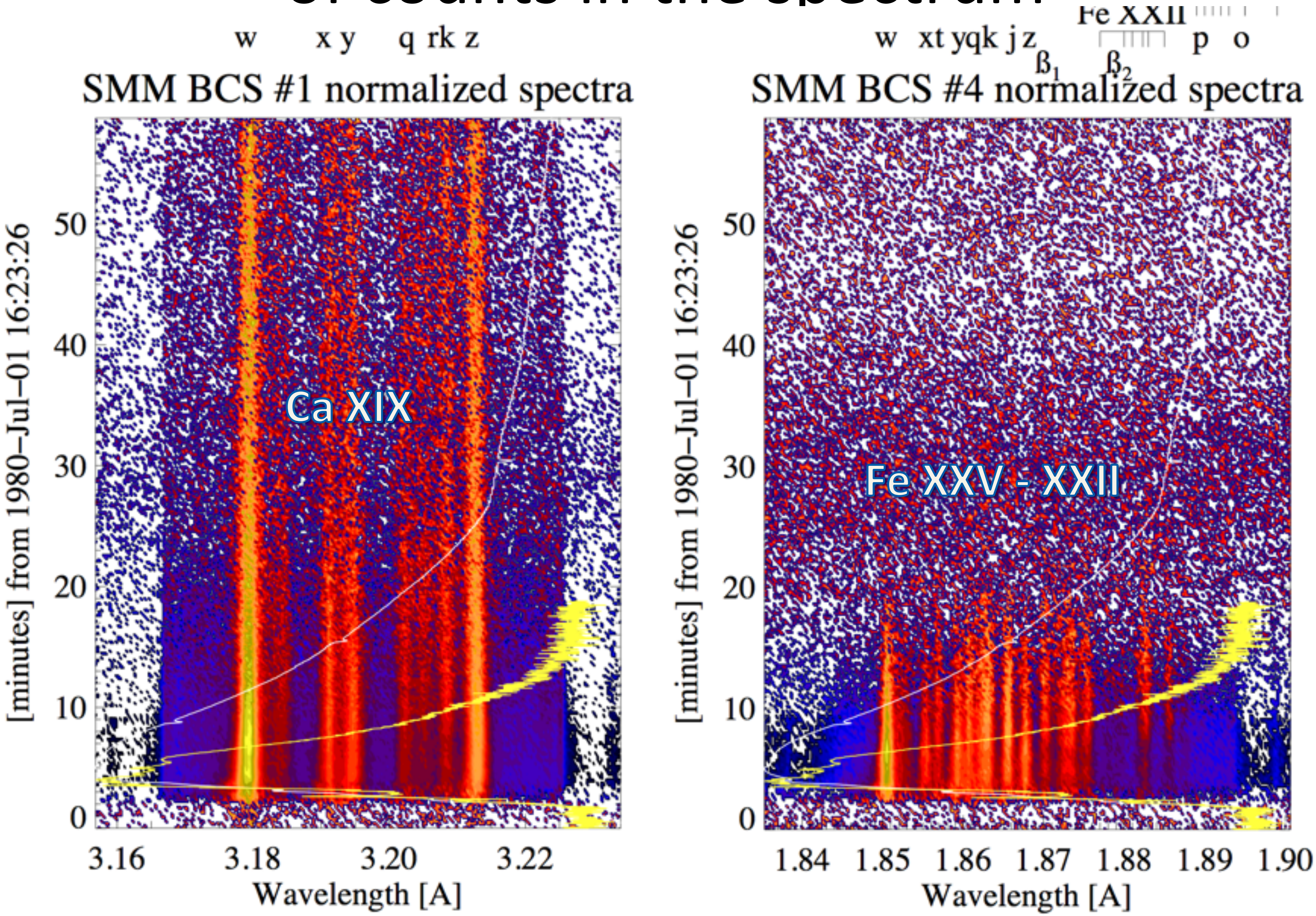
Flare-integrated spectra (adjusted)



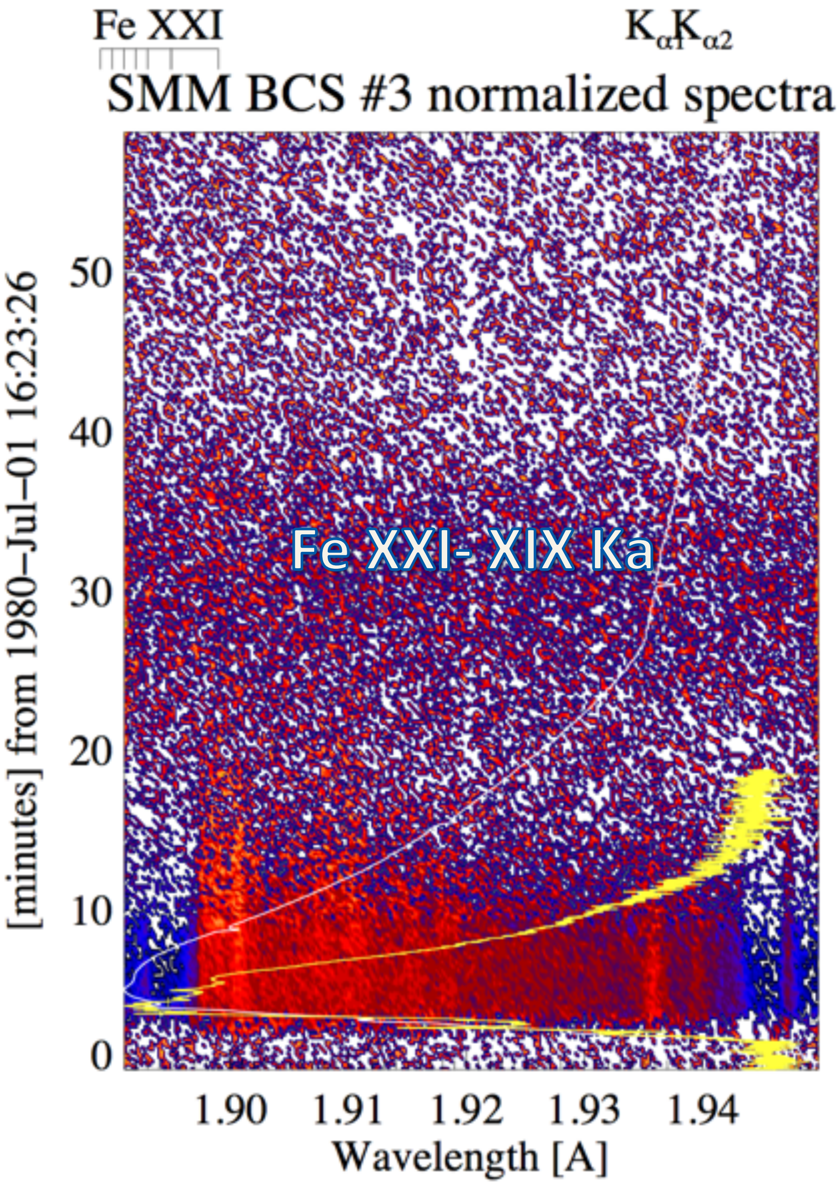
Projected width of collimator FWHM

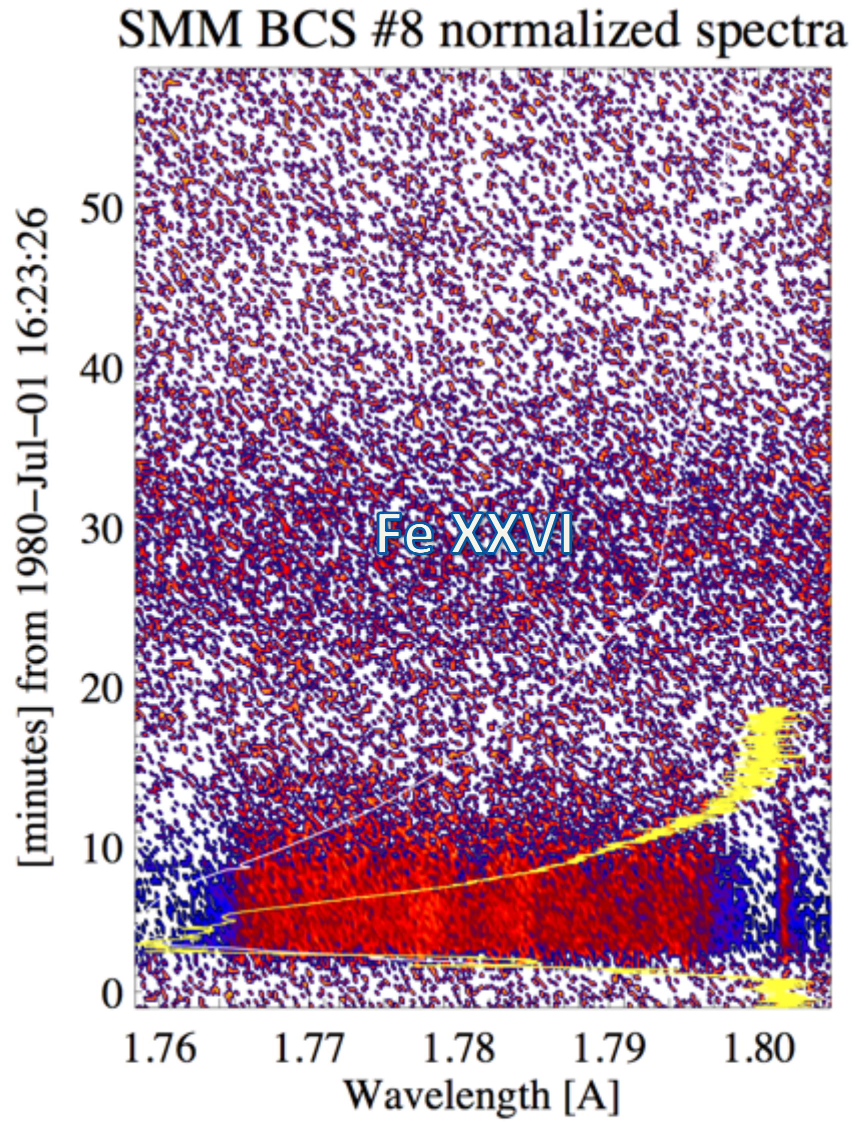


Spectra evolution: normalized to total No. of counts in the spectrum

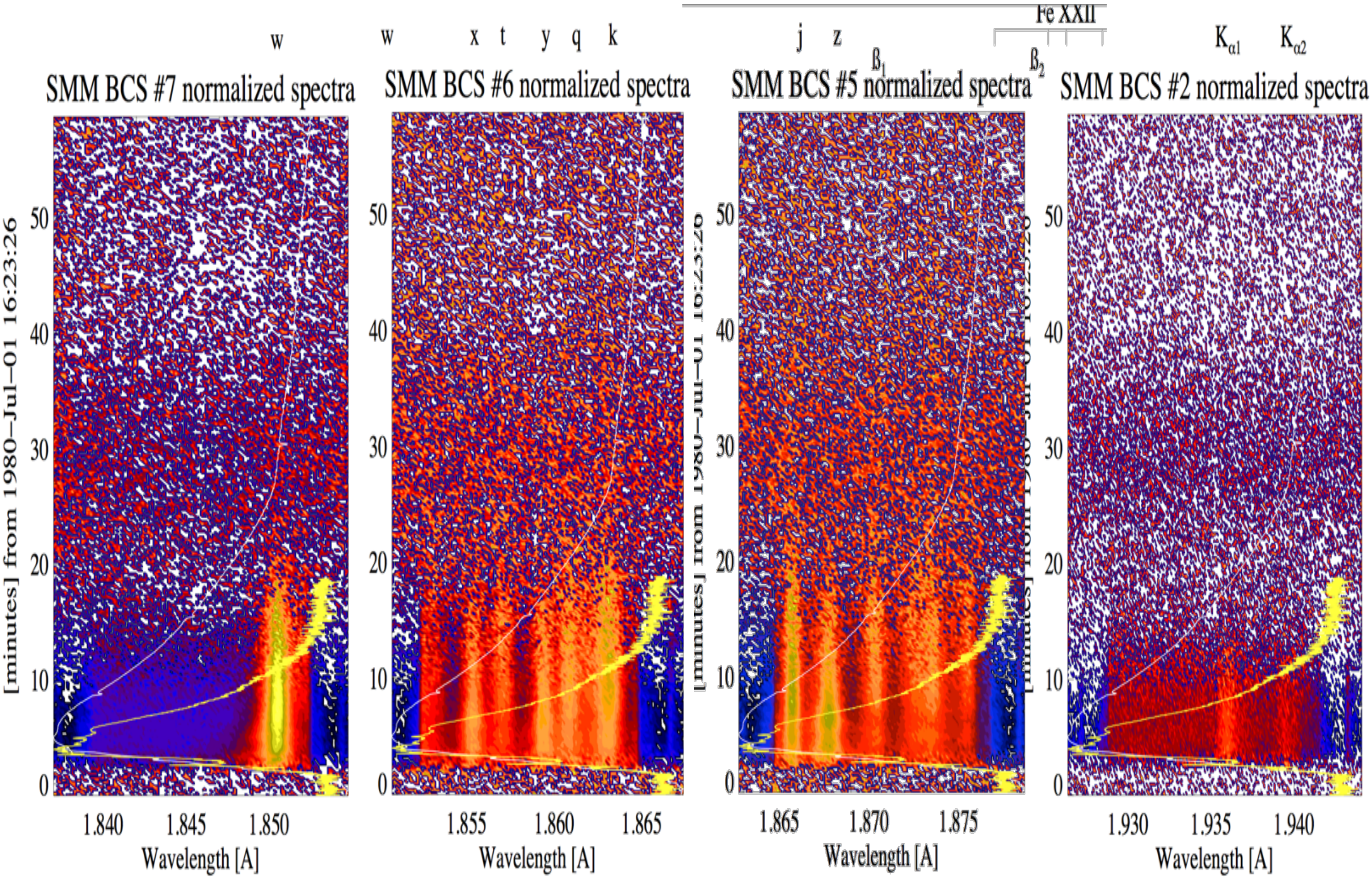


Spectra evolution: normalized to total No. of counts in the spectrum

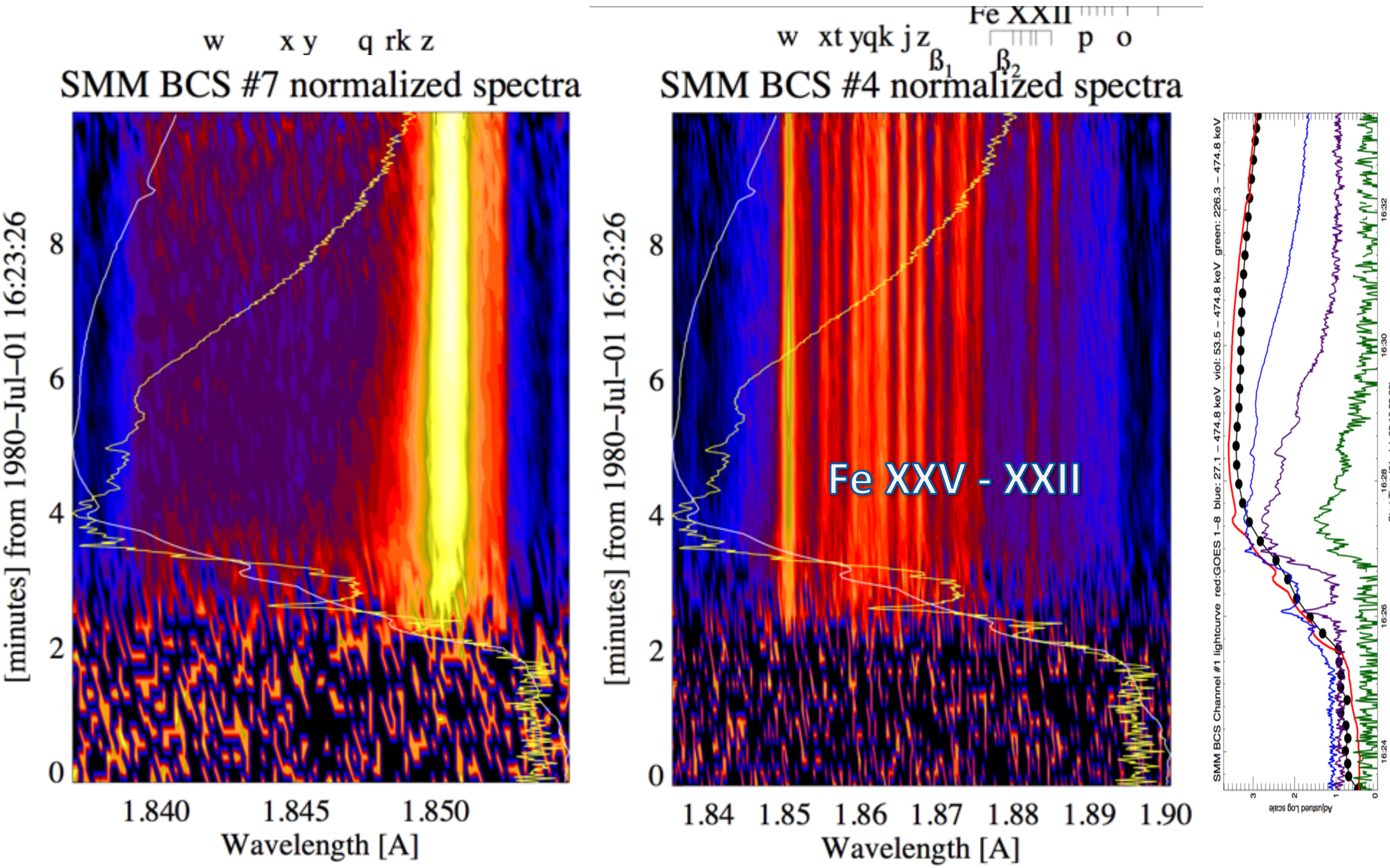




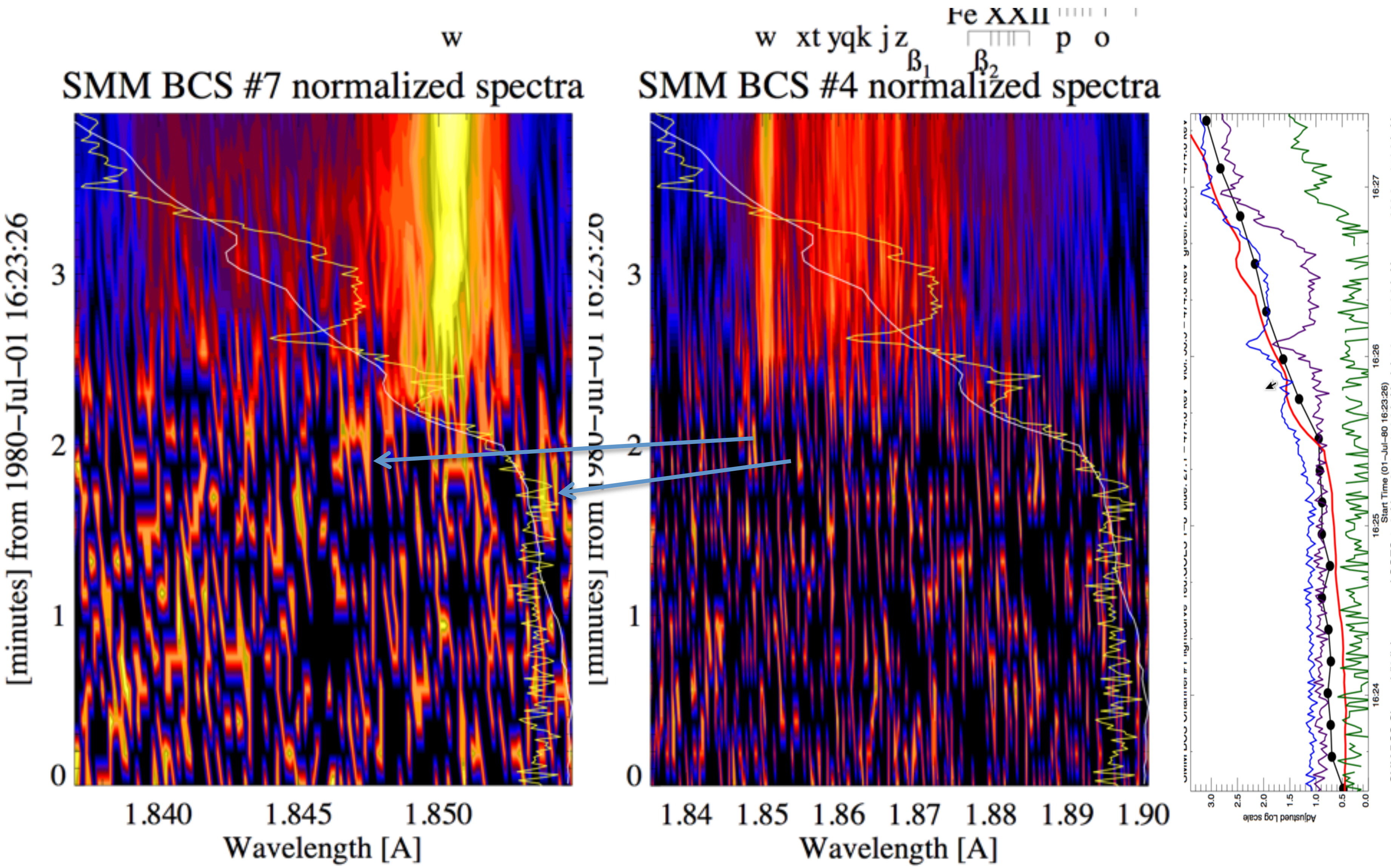
evolution in high-spectral resolution



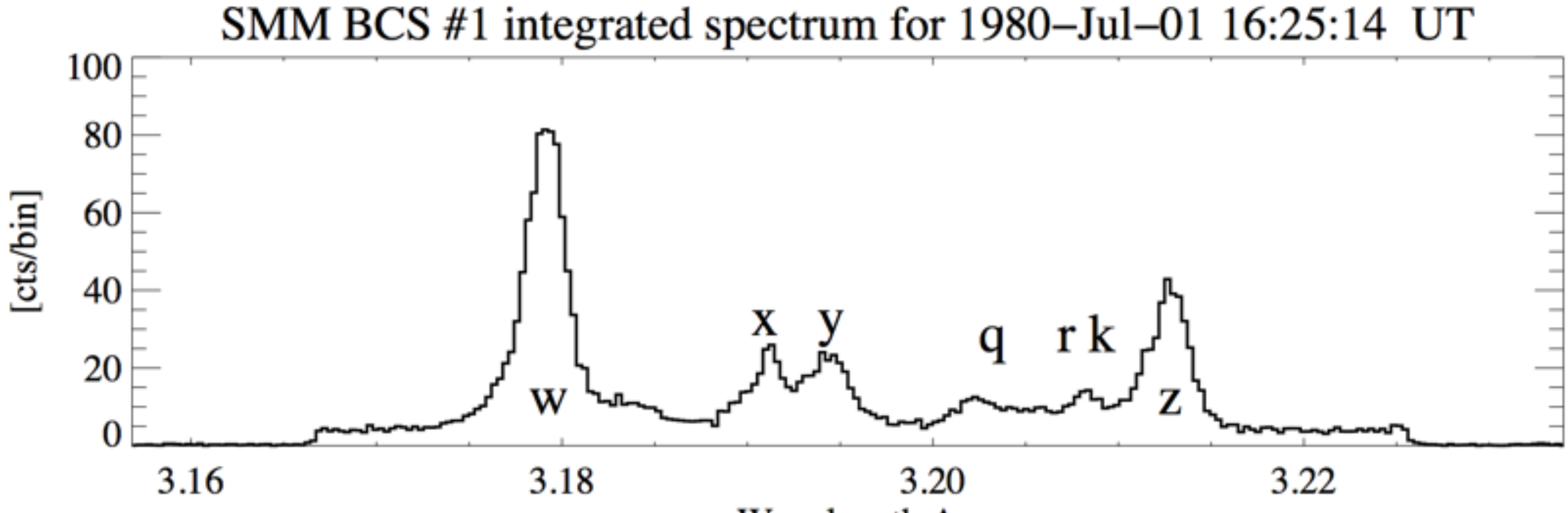
Spectra evolution: early few min

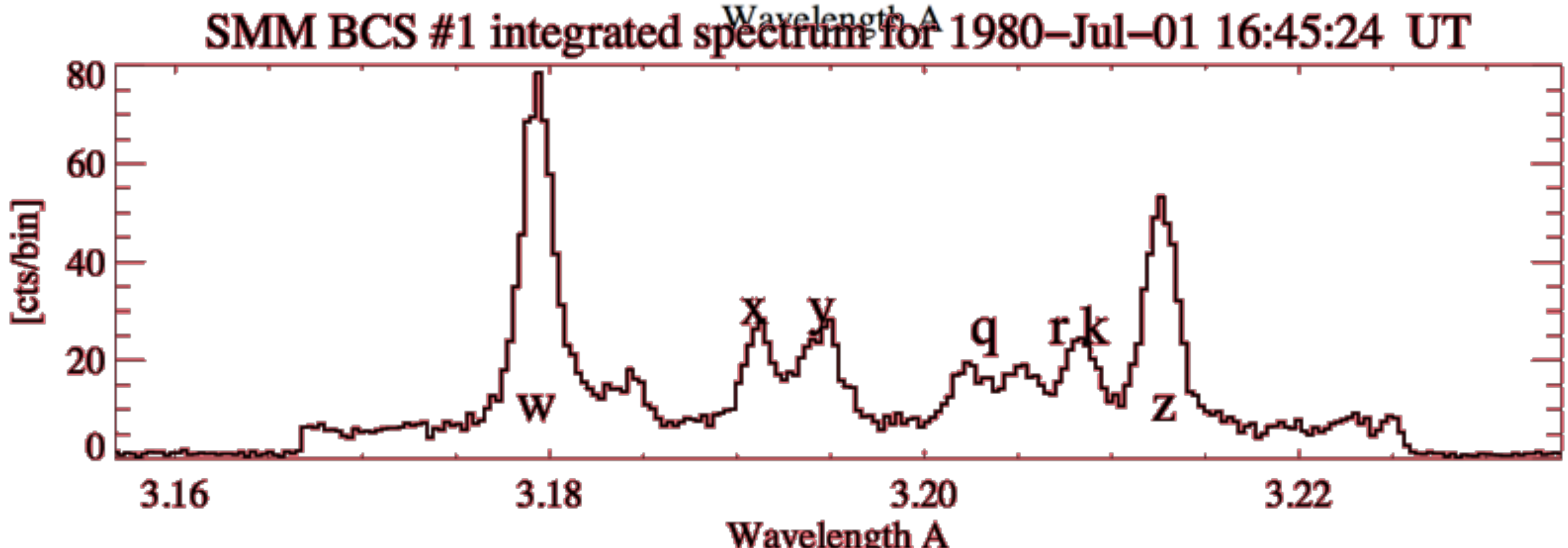


Spectra evolution: very early min

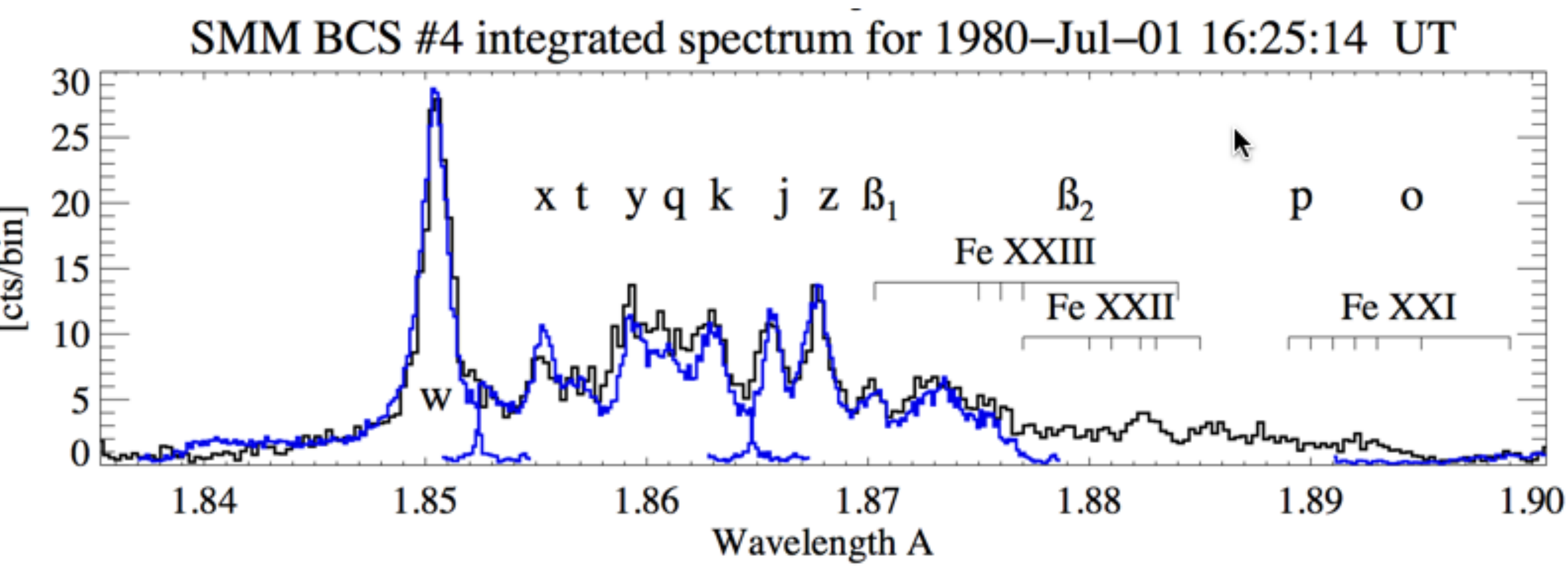


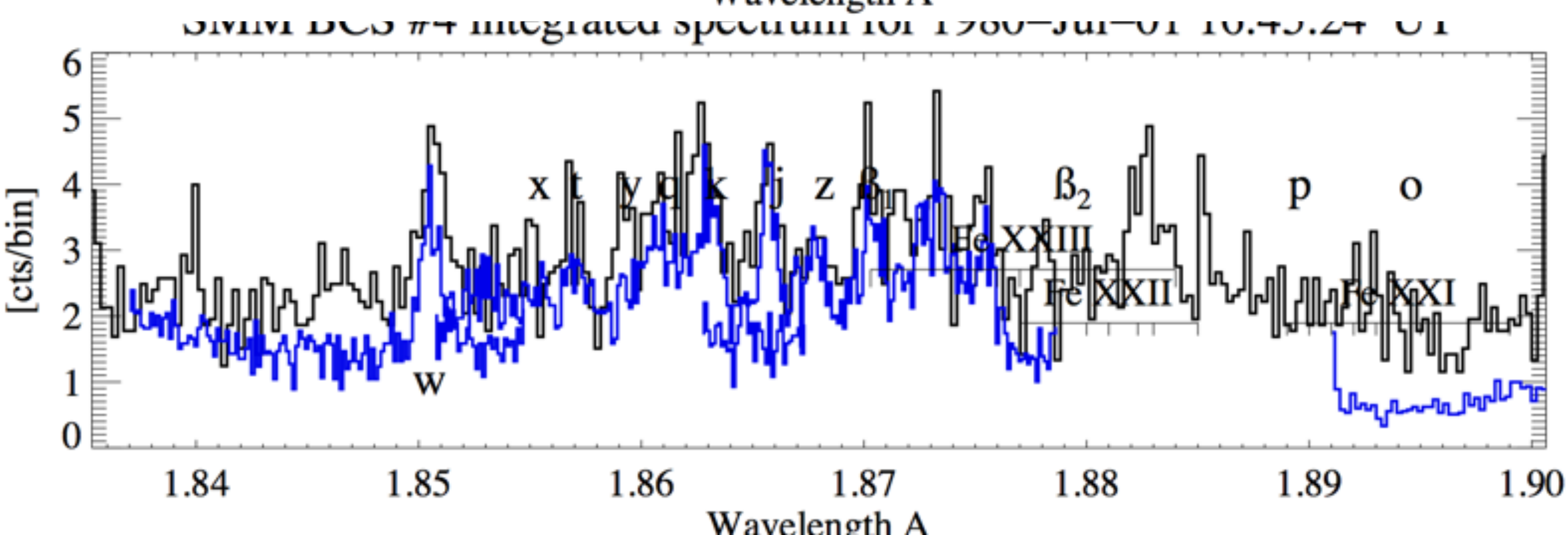
Impulsive vs decay phase spectra Ca



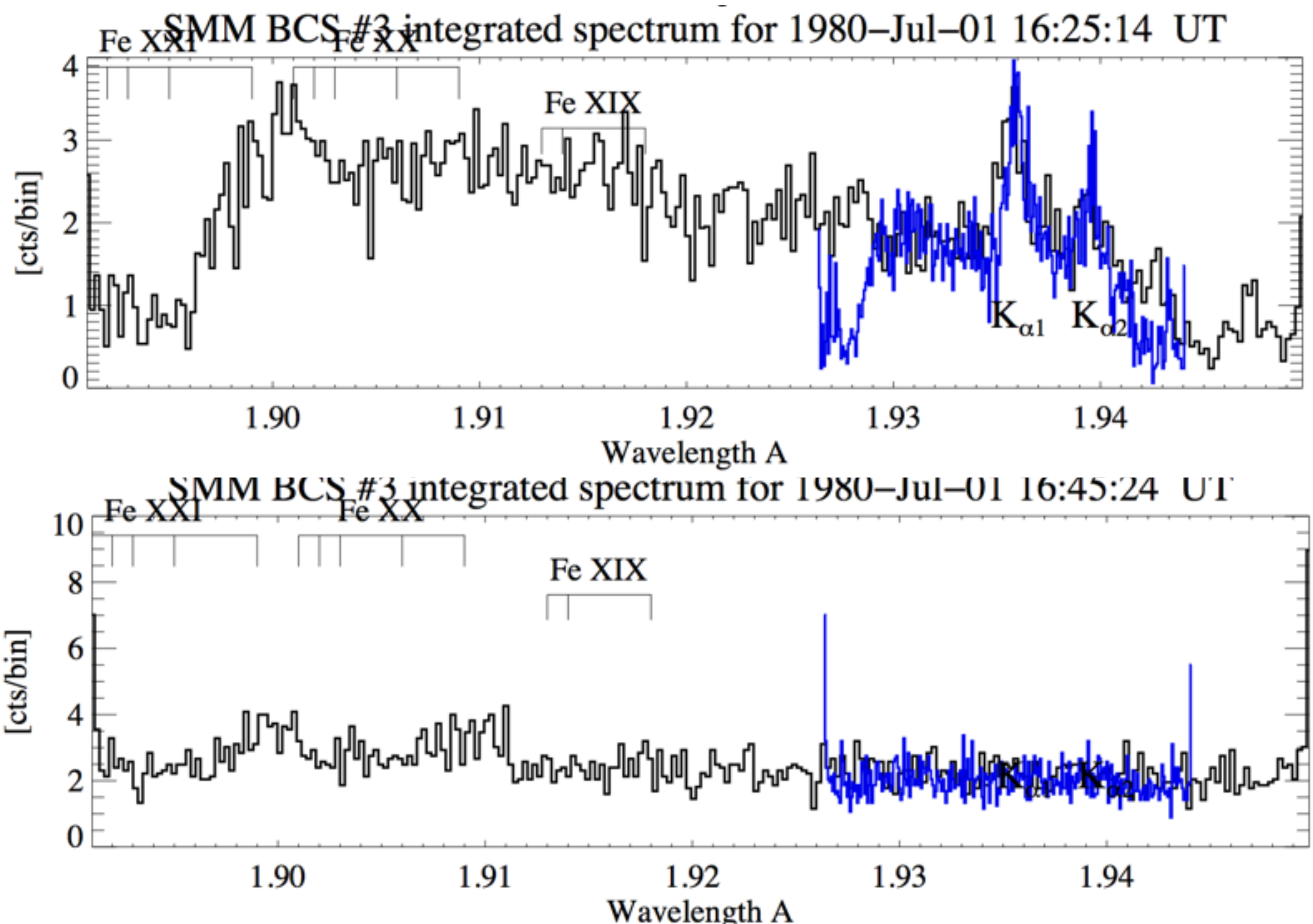


Impulsive vs decay phase spectra Fe

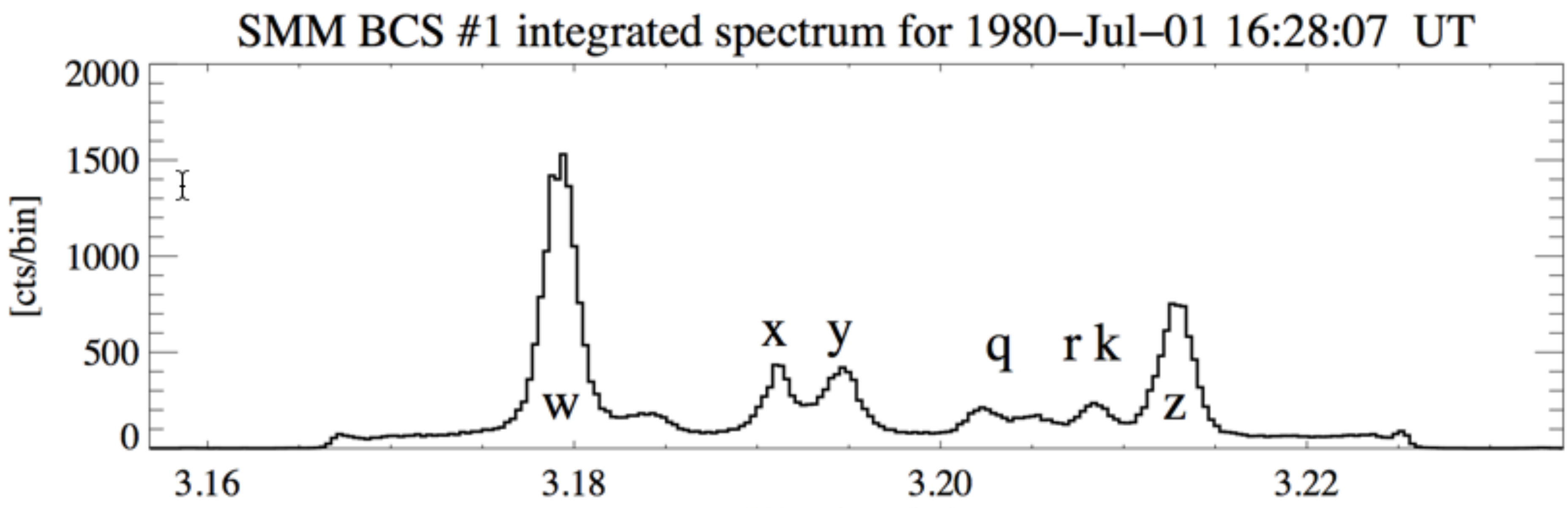


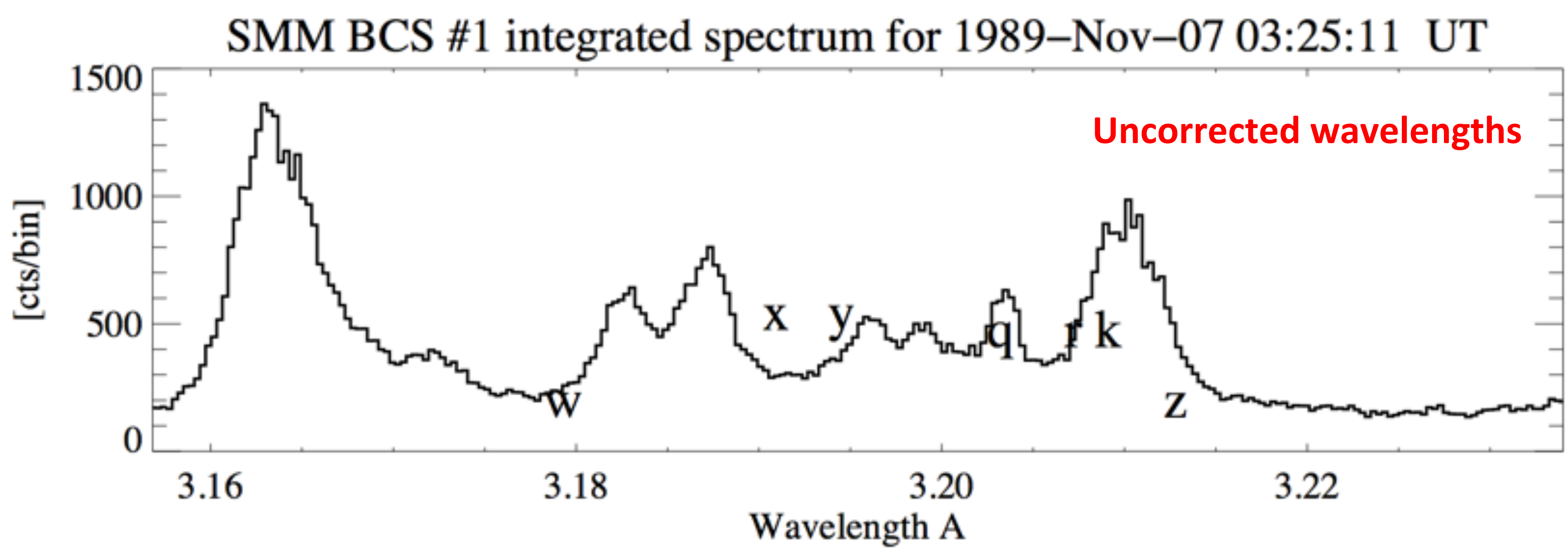


Impulsive vs decay phase spectra Fe Ka

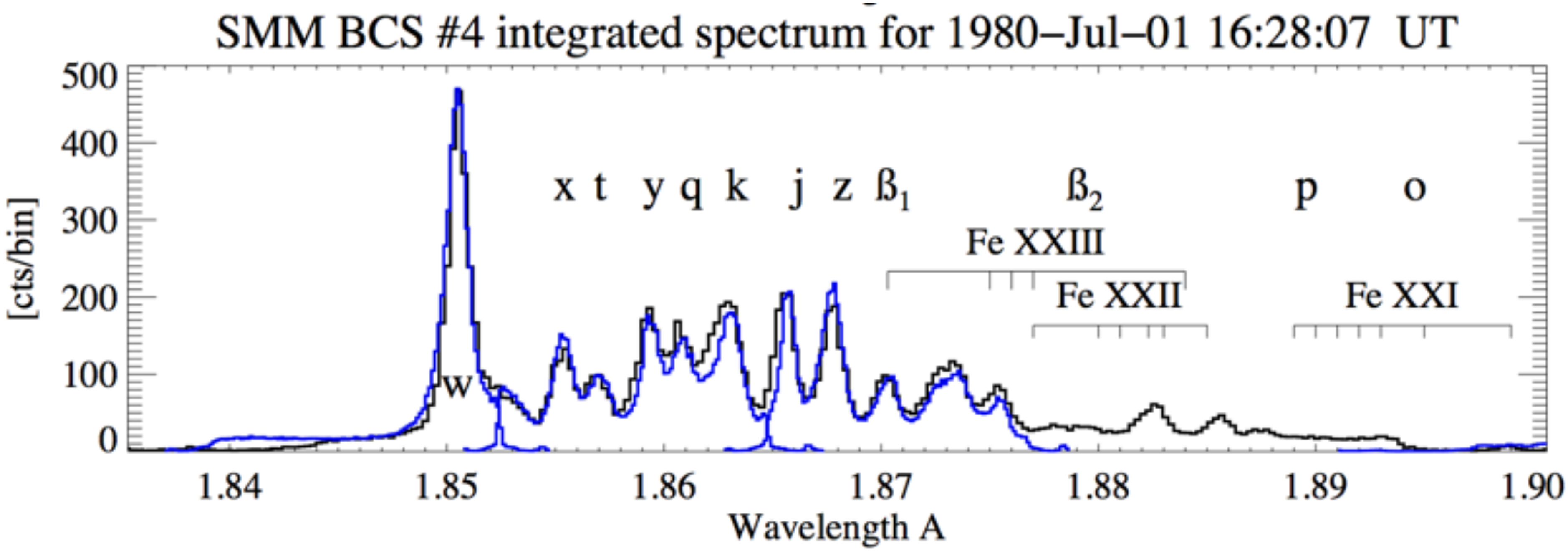


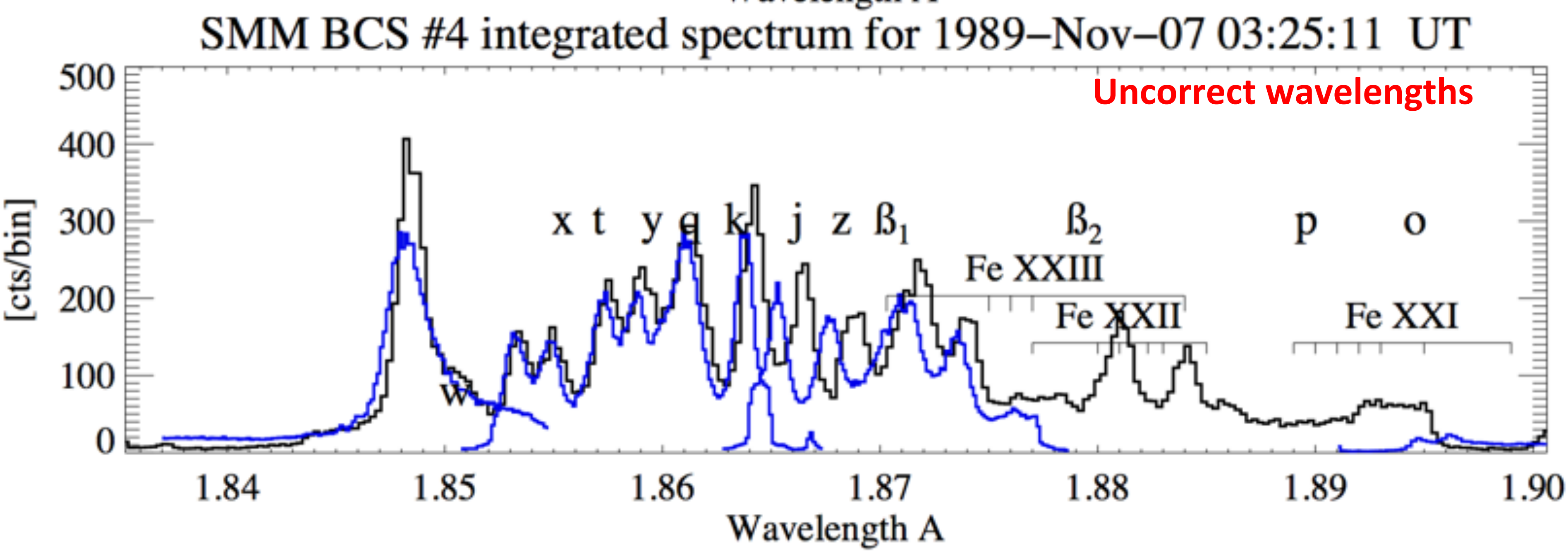
Early (1980) and late (1989) observations



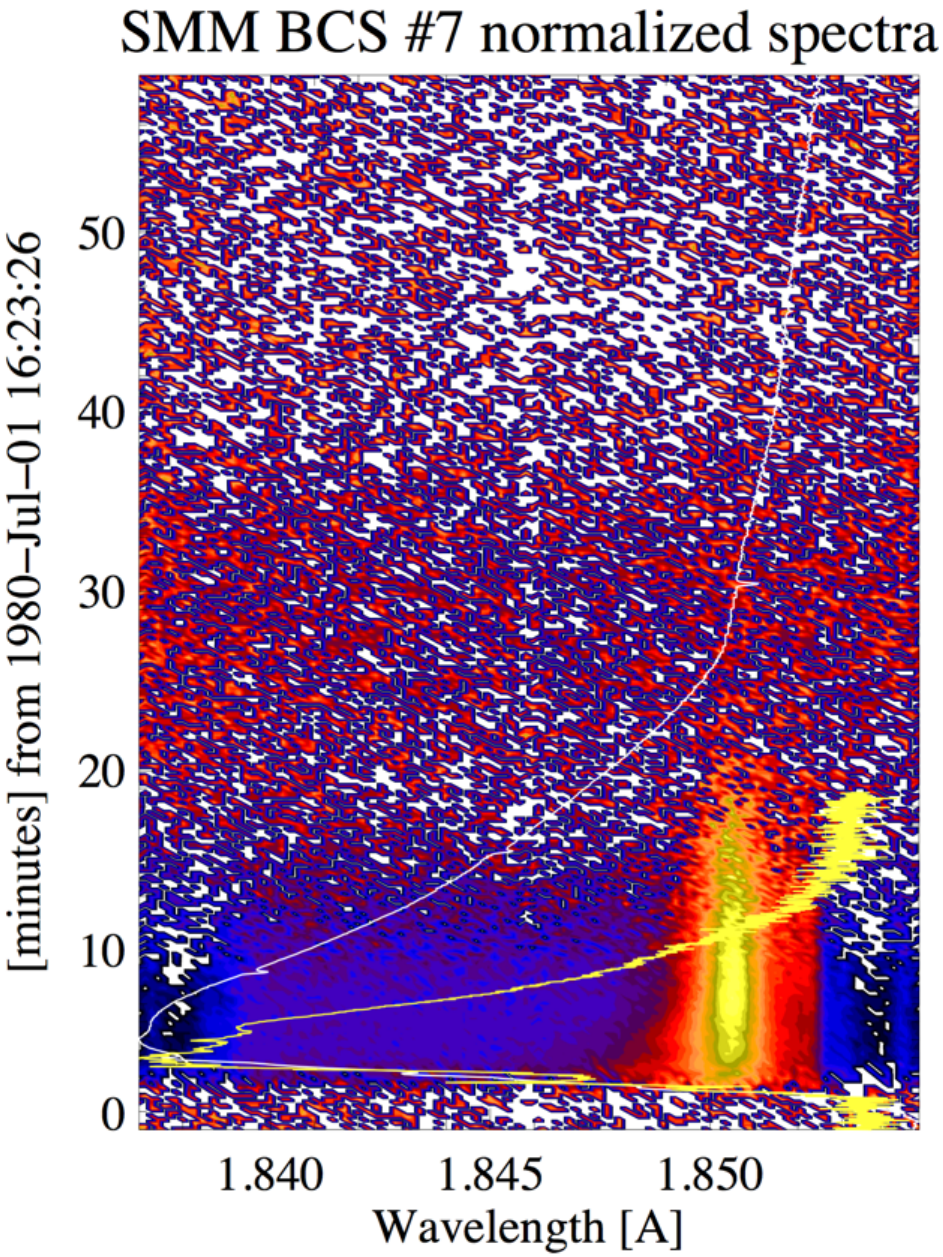


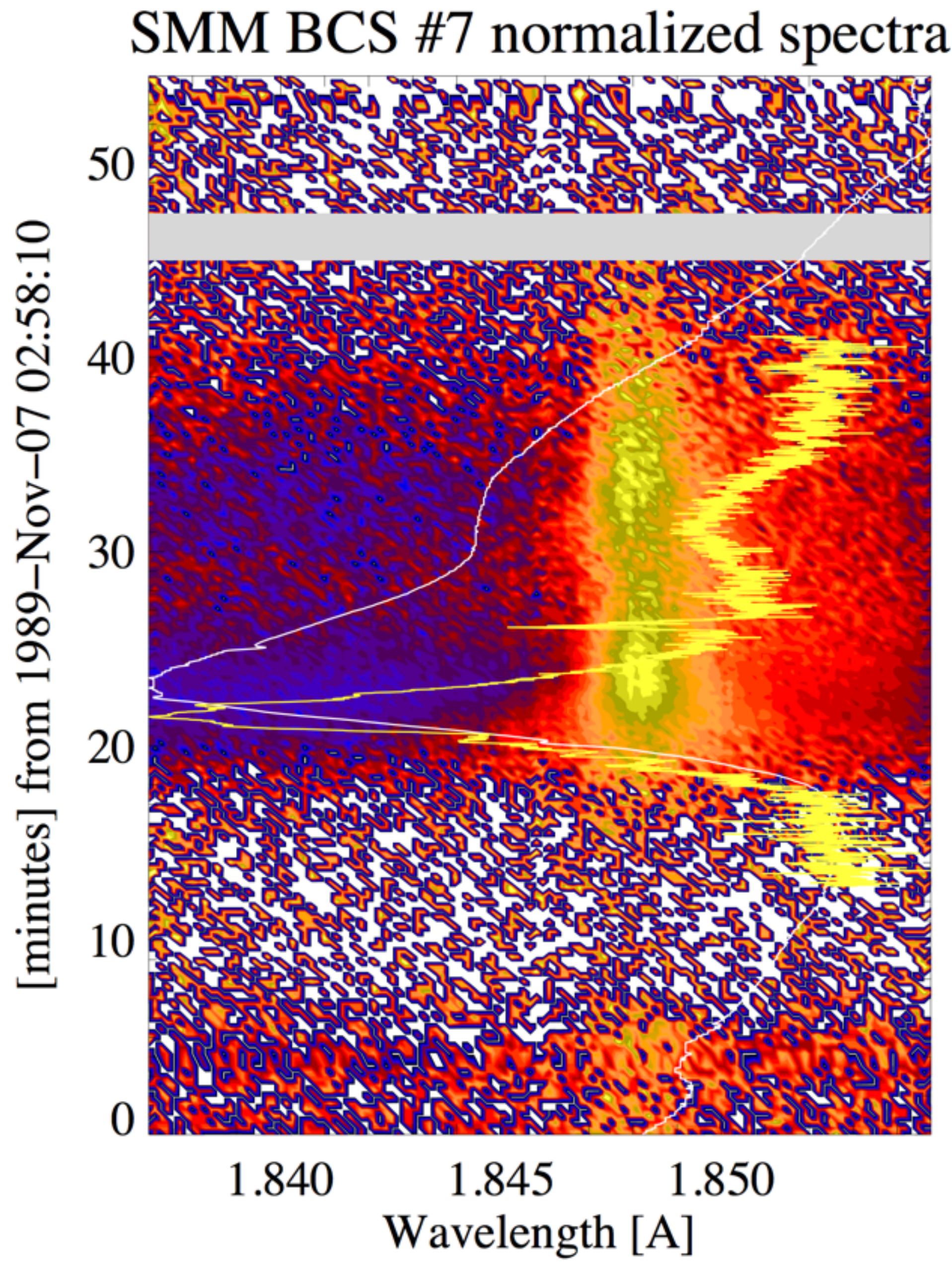
Early (1980) and late (1989) observations



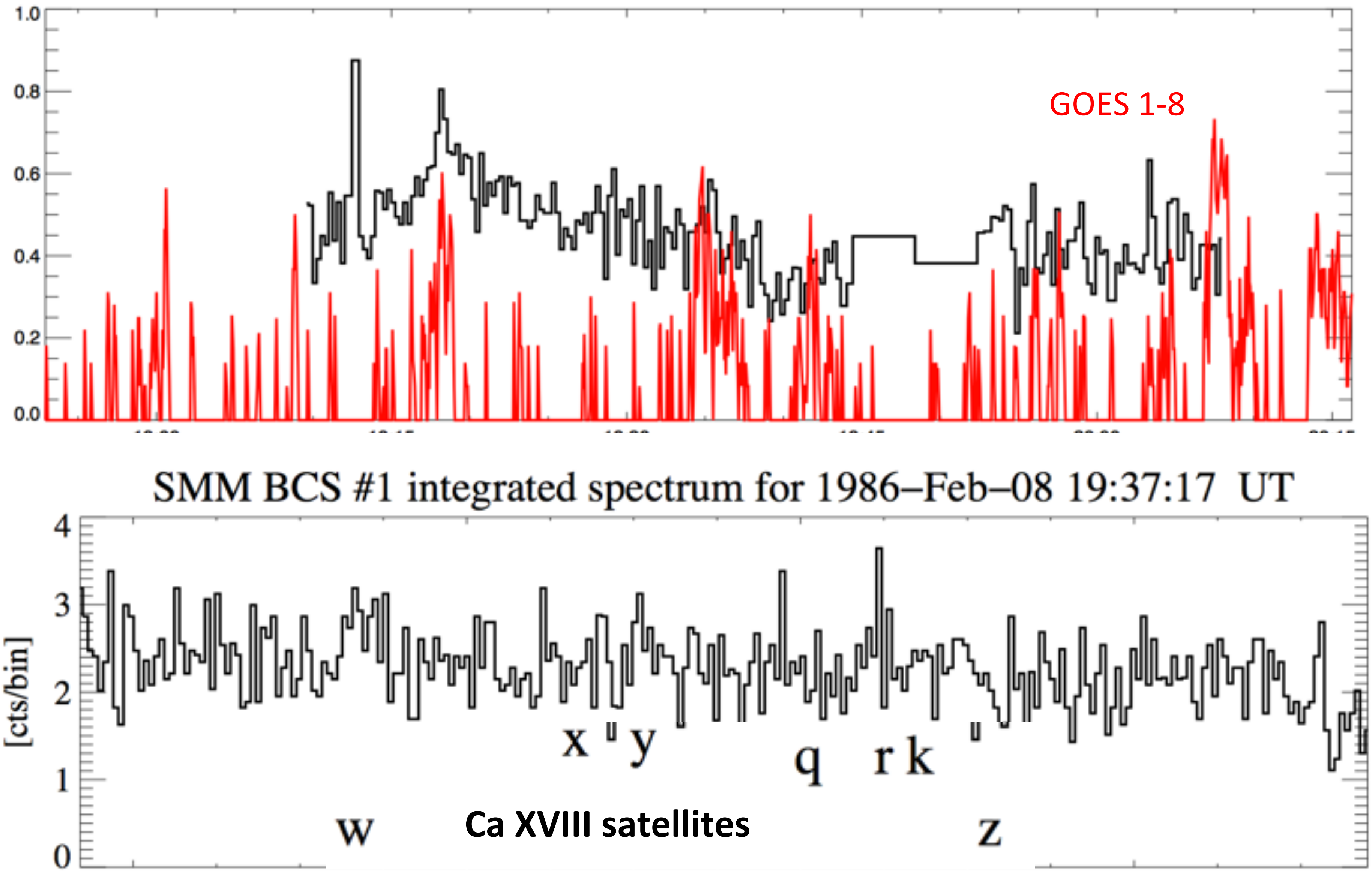


Interesting Channel #7: Fe XXV w

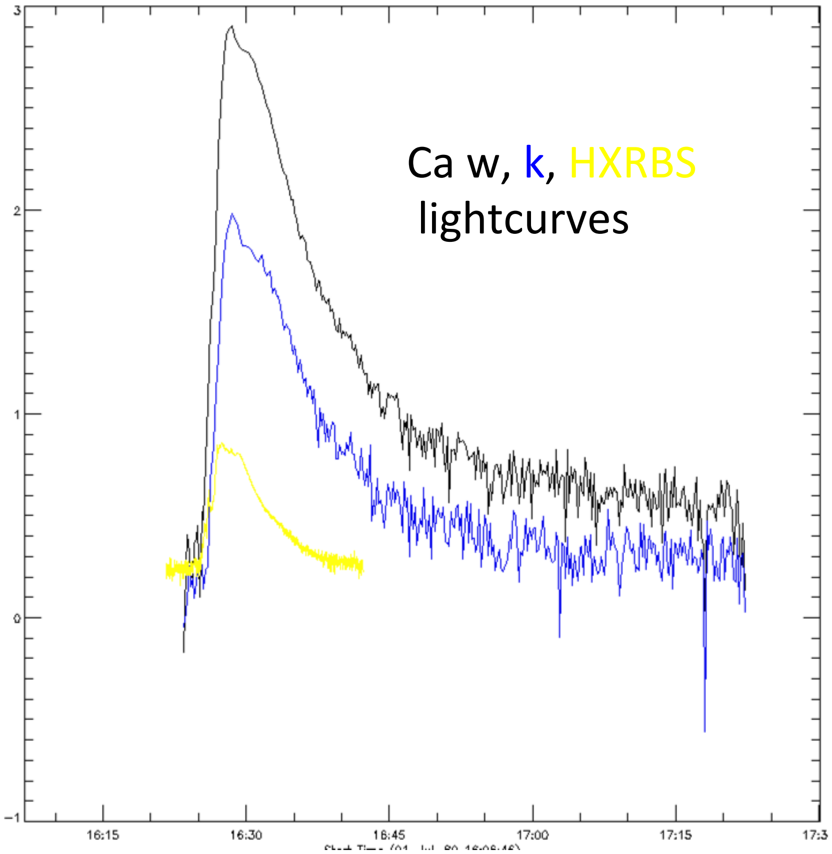


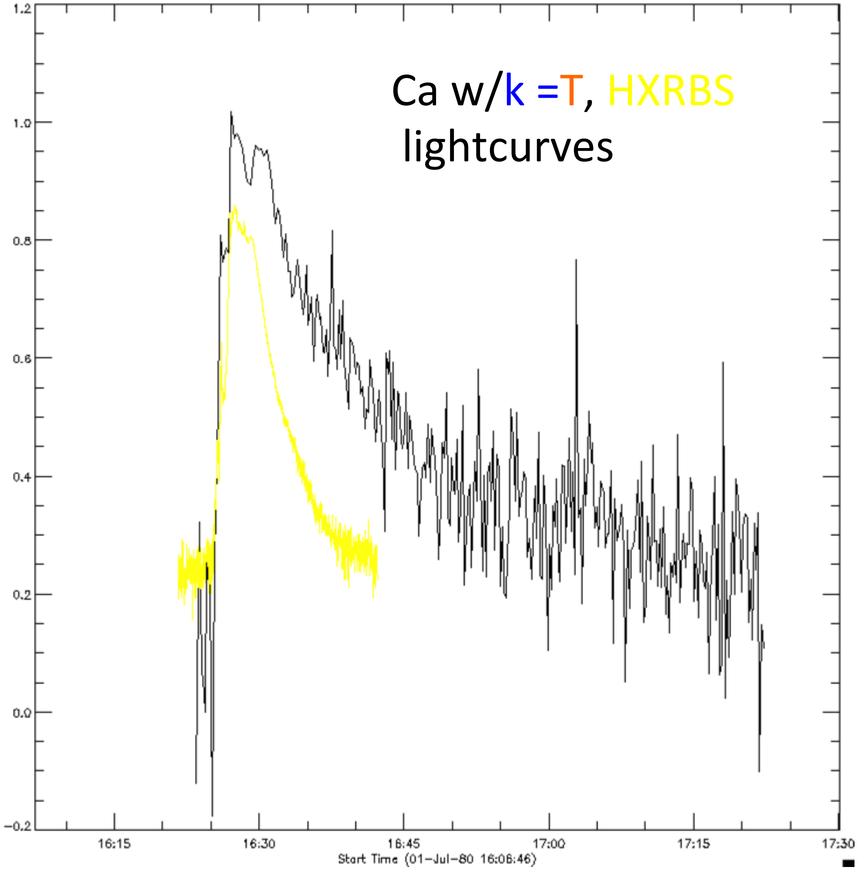


Microflare signatures if within FOV

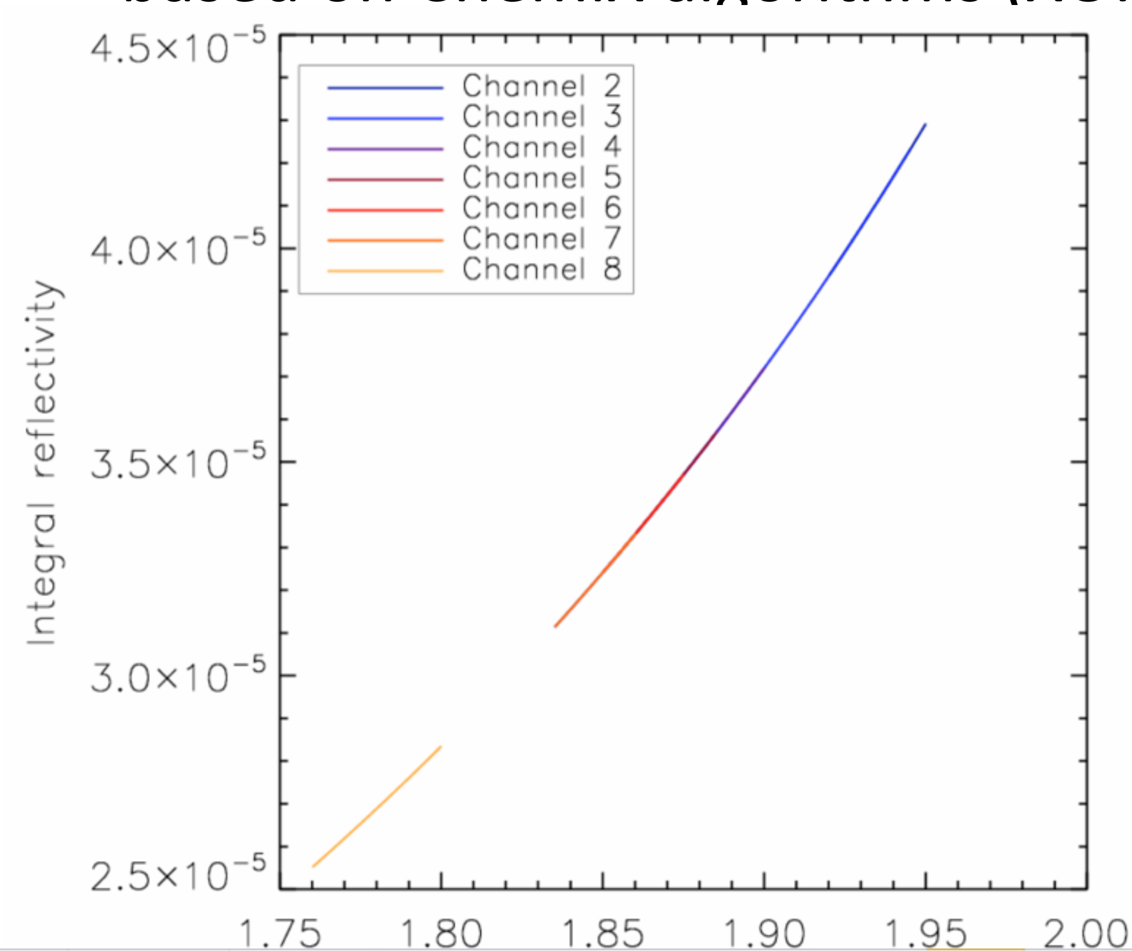


Lightcurves in selected lines





New crystal & SBCS eff. Areas (Zaneta) based on ChemiX algorithms (XOP)



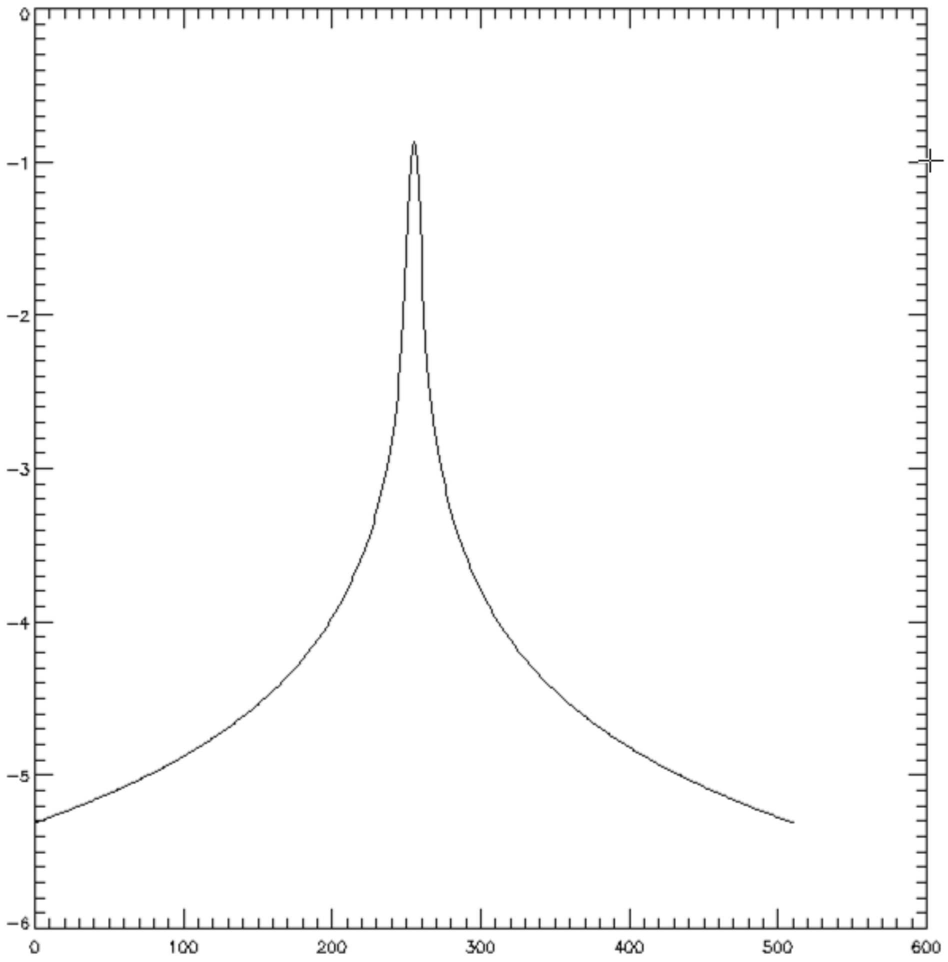
				Rapley 1976					XOP 2.3			
No	Crystal	Crystal dimensions [r	Bent radius [m]	2d spacing [A]	Crystal rocking curve FW	Integral reflectivity [rad]	Integral reflec	Peak reflec	2d spacing	Crystal rocki	Integral reflectivity	Peak reflectivity
1	Ge 220	160 x 30 x 1	5.642	4,00066	0,000145444	3,00E-05	1,03E-04		4,000351	0,00013228	0,00011288	0,724453
2	Ge 422	160 x 30 x 1	11.474	2,30978	4,85E-05	4,00E-05	3,35E-05		2,309603	4,17E-05	4,11E-05	0,853892
3	Ge 422	160 x 30 x 1	3.683	2,30978	4,85E-05	4,00E-05	3,35E-05		2,309603	3,78E-05	3,71E-05	0,848235
4	Ge 422	160 x 30 x 1	3.902	2,30978	4,85E-05	4,00E-05	3,35E-05		2,309603	3,49E-05	3,41E-05	0,843819
5	Ge 422	160 x 30 x 1	16.112	2,30978	4,85E-05	4,00E-05	3,35E-05		2,309603	3,53E-05	3,45E-05	0,844451
6	Ge 422	160 x 30 x 1	16.325	2,30978	4,85E-05	4,00E-05	3,35E-05		2,309603	3,44E-05	3,36E-05	0,843041
7	Ge 422	160 x 30 x 1	16.507	2,30978	4,85E-05	4,00E-05	2,80E-05		2,309603	3,31E-05	3,22E-05	0,841008
8	Ge 422	160 x 30 x 1	8.434	2,30978	4,85E-05	4,00E-05	2,30E-05		2,309603	2,78E-05	2,69E-05	0,832193

However some lines are blended

we developed DEM- based approach to remove the instrumental broadening

- We use W-S deconvolution
- Emission functions are the instrument Voigt profile
- Input data (observed fluxes) are the fluxes in bins
- We assume constant first approximation for DEM deconvoved spectra

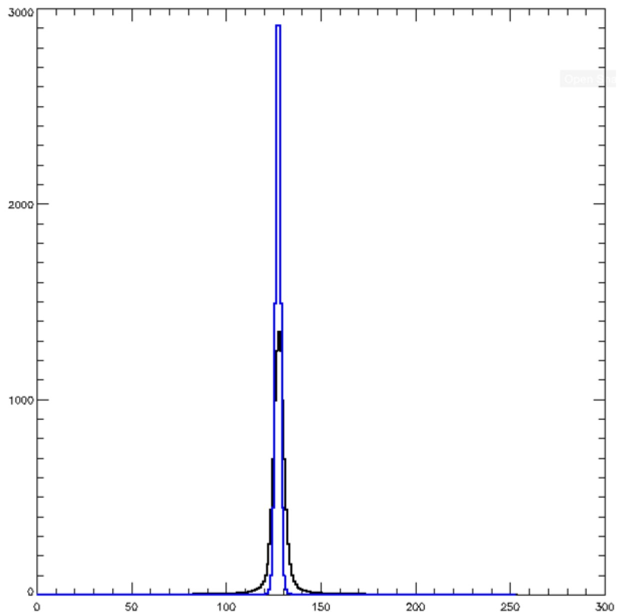
Voigt profile



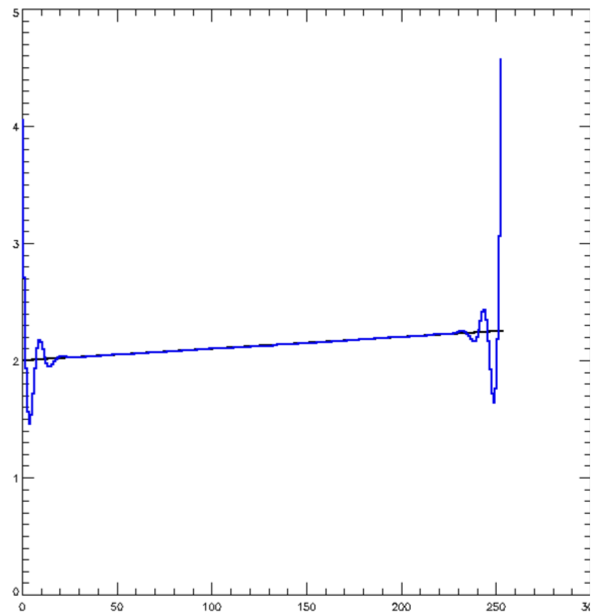
SolarSoft mvoigt(xx,a,pder)

```
• a=replicate(0,7) ; set-up a-vector
• ; a[0,1,2]=coefficients of quadratic background, taken zero
• a[3]=1.e6 ; line intensity
• a[4]=255 ; line center
• ; setting defaults
• a[5]=3.0 ; 1/e Doppler width in units of bin
• a[6]=1.5 ; rocking width (1/e units)
• if keyword_set(a5) then a[5]=a5
• if keyword_set(a6) then a[6]=a6
• nor_lor=mvoigt(xx,a,pder) ; calculates profile
• nor_lor=nor_lor/total(nor_lor) ; normalize line profile to unit integral
```

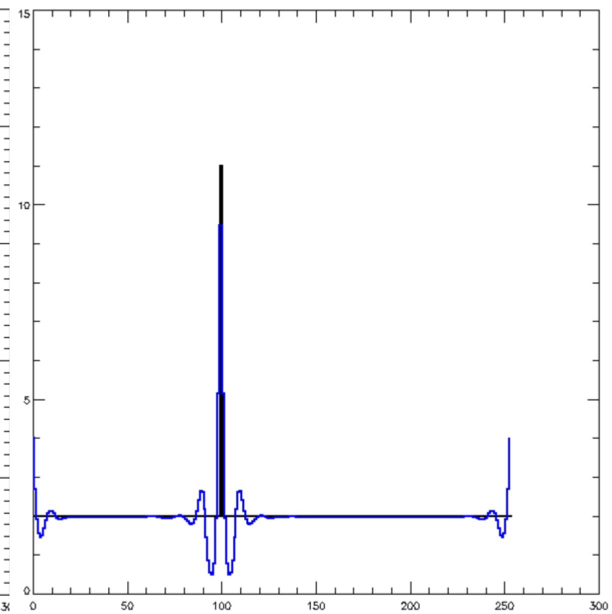
How line deconvolution works



Single bin on input, 1000 iter



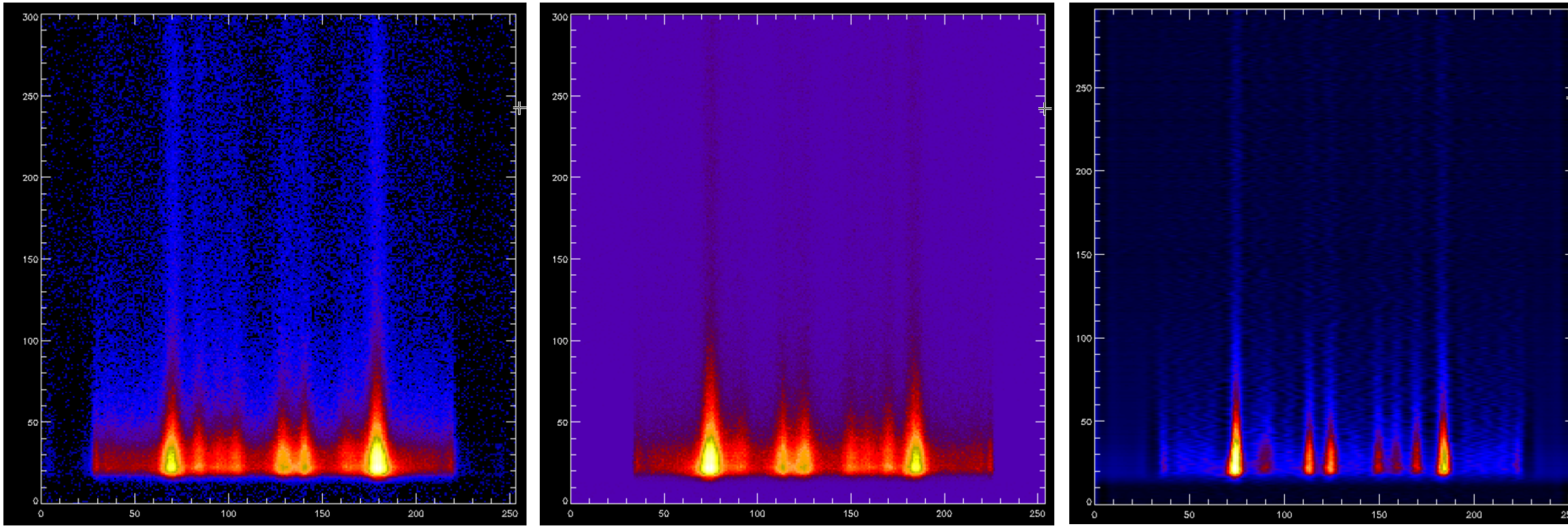
Inclined cont. on input, 1000 iter



Cont+ Single bin on input, 1000 iter

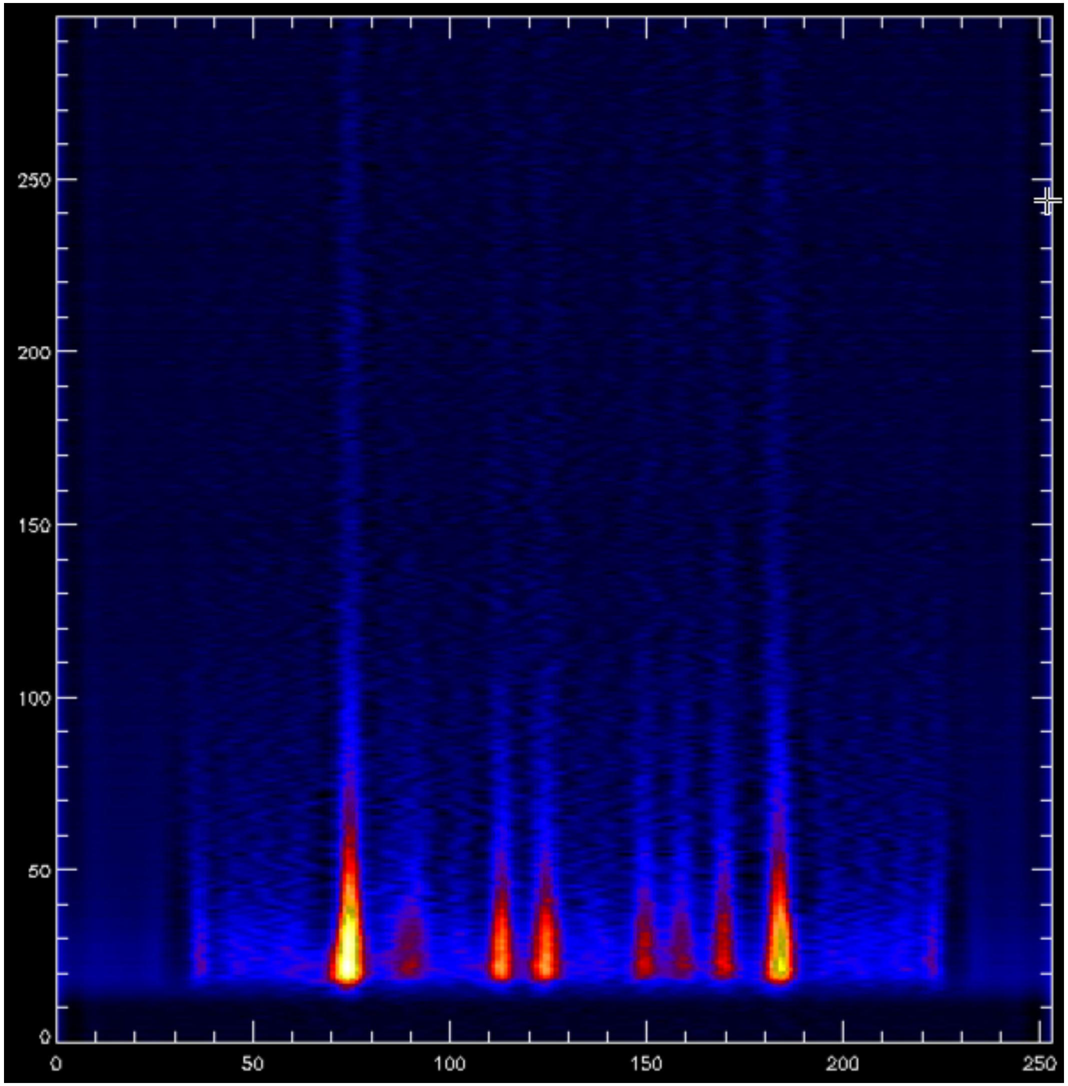
- Solutions always positive, Bayesian→ „detect” lines from spectra, collecting the flux and determining the position.

Comparison of original, cleaned & deconvolved



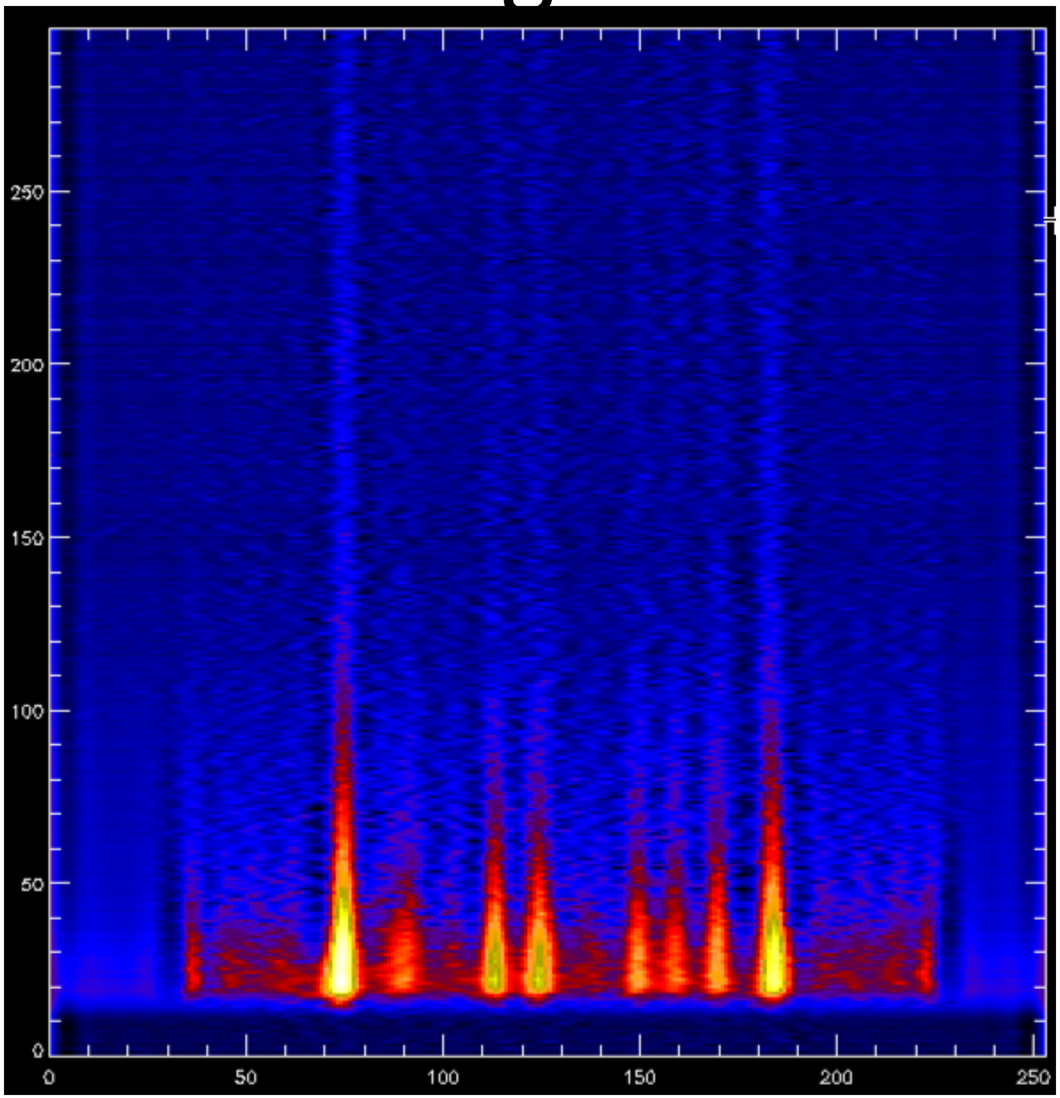
- Effects removed for cleaned spectra:
  - orbital background through analysis of hidden bins, we interpolate background for every bin
  - Continuum established
- On deconvolved:
  - continuum subtracted
  - Add1 for the positive result
- On result:

What we see on deconvolved spectra



- Why it is so consistent?
- We actually detect presence of spectral features since the W-S deconvolution is always positive and finds optimal solution (Bayesian approach) from existing data, even single counts
- No a priori assumptions on spectral feature location on bin scale

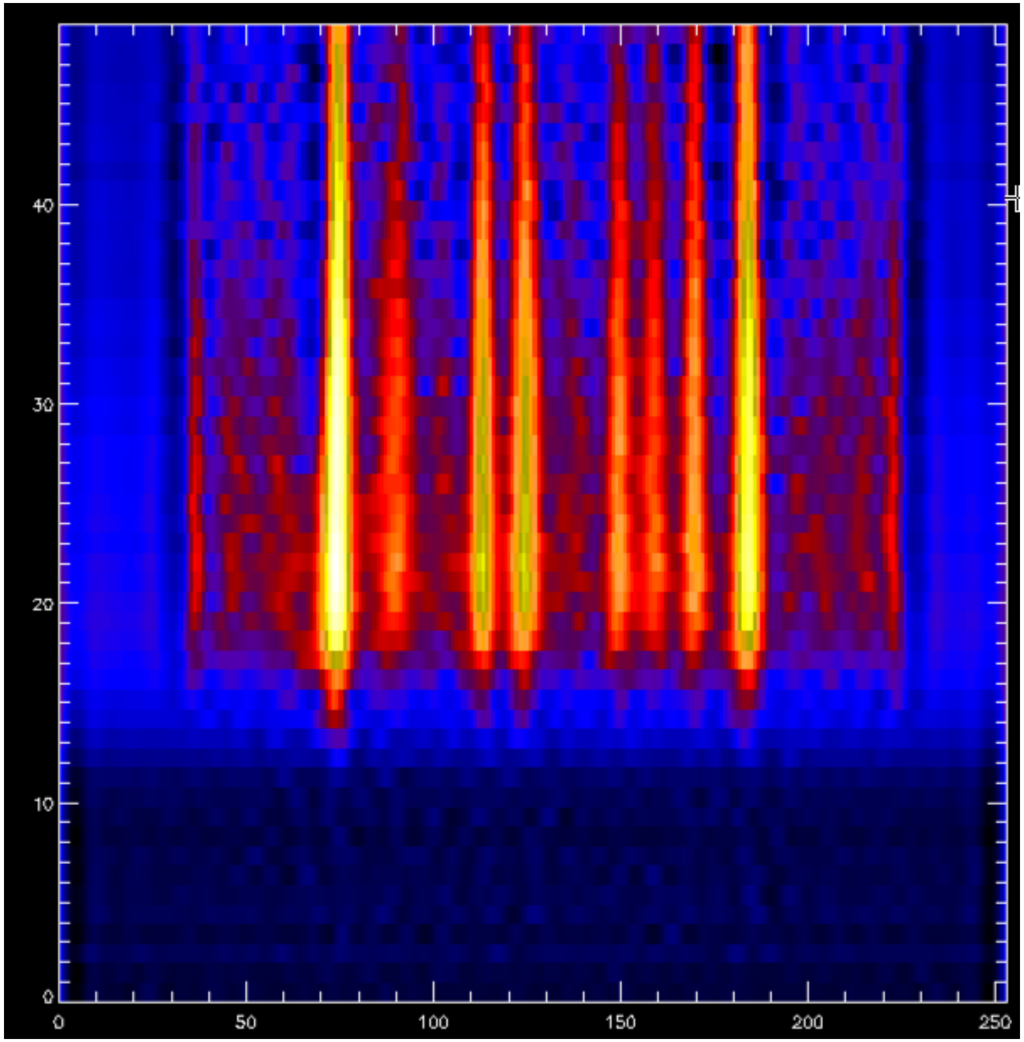
Enlarged deconvolved



image_c,spectrum_lc1[*,3:*]^0.05

- vibrating, but Stable position of lines at low intensities
- If correlated may have some physical meaning

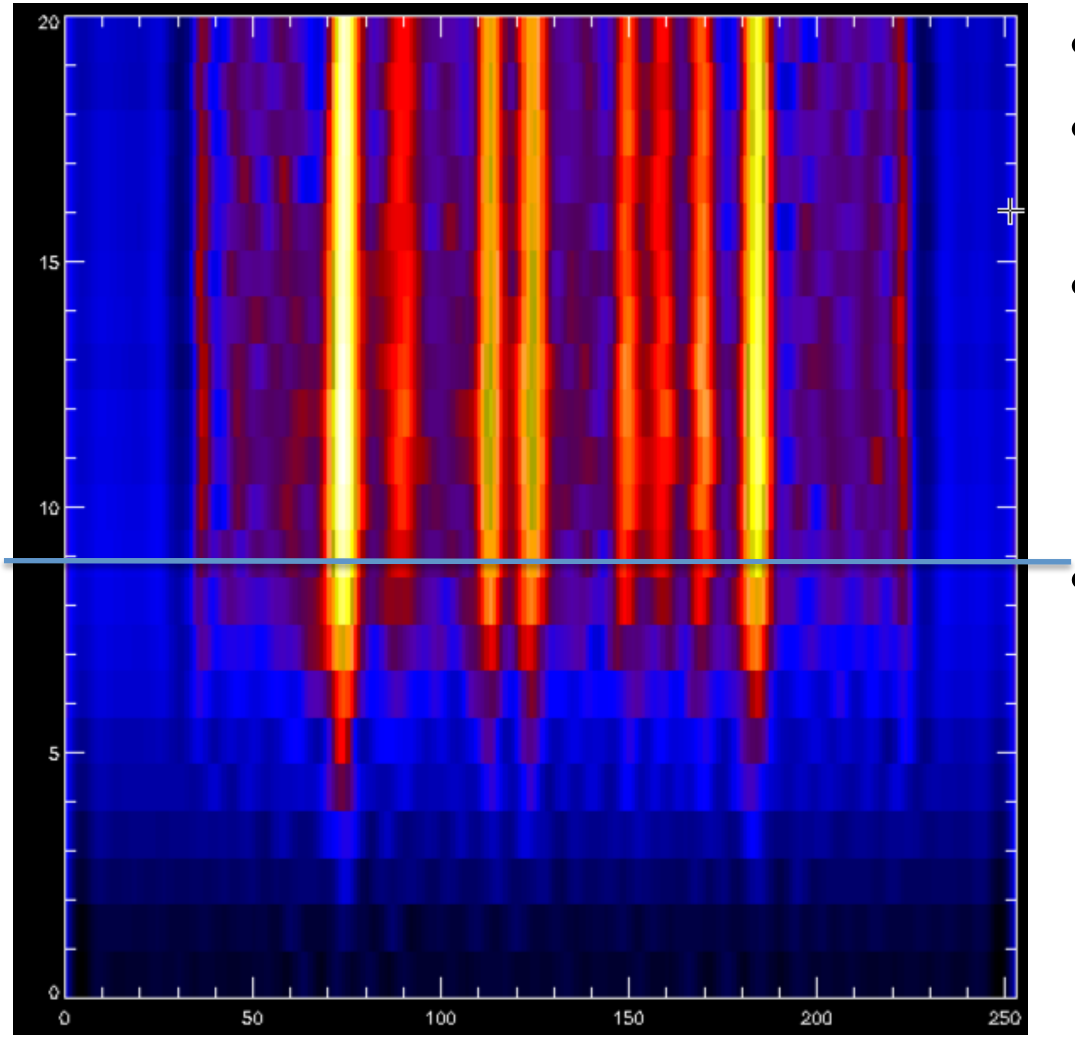
Deconvolved lowlevel Enhanced



image_c,spectrum_lc1[*,3:3+49]^0.05

- Clearly seen is timing of flare emission arrival
- The spectral image is normalized to the total intensity over the instant spectrum

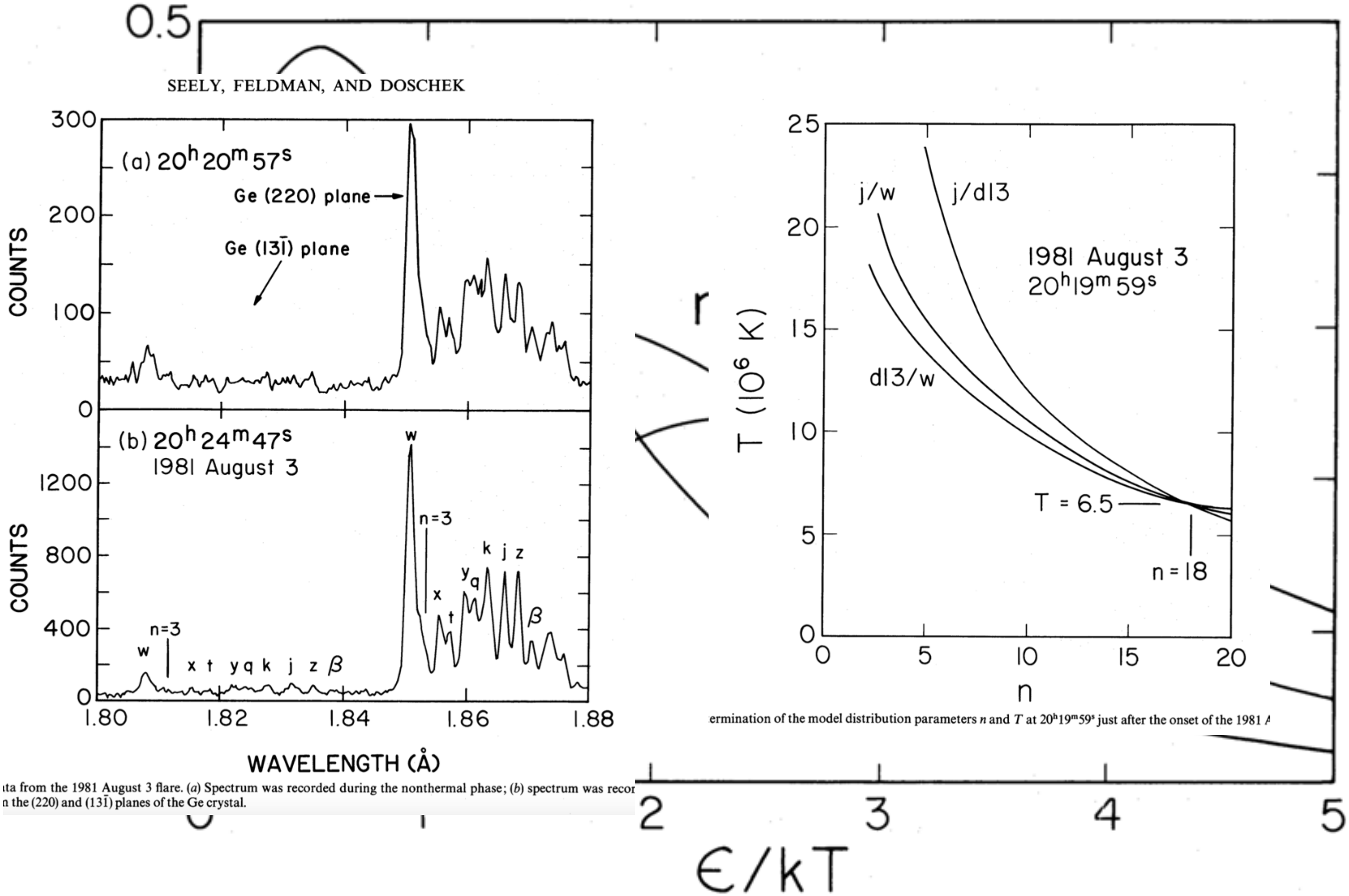
deconvolved very early phase DGI=17s



image_c,spectrum_lc1[*,3:3+49]^0.05

- w, x, y & z first
- q & r somewhat delyed
- Slight bias? of DE against direct excitation and/or innershell exitation
- Electron spectra too hard? Not enough softer electrons at the resonance energies?

THE ASTROPHYSICAL JOURNAL, 319:541–554, 1987 August 1



...ata from the 1981 August 3 flare. (*a*) Spectrum was recorded during the nonthermal phase; (*b*) spectrum was recor...
...n the (220) and (13$\bar{1}$) planes of the Ge crystal.

...ermination of the model distribution parameters n and T at $20^h19^m59^s$ just after the onset of the 1981 A...

FIG. 3.—Model electron energy distribution for $n = 1$ (Maxwellian) and for $n = 3$ and $n = 5$ (nonthermal)

Transient effects

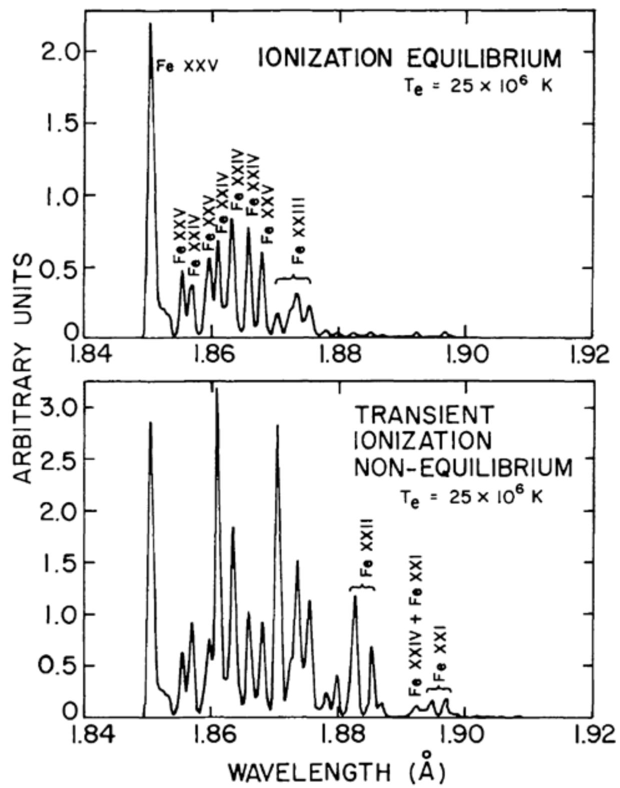
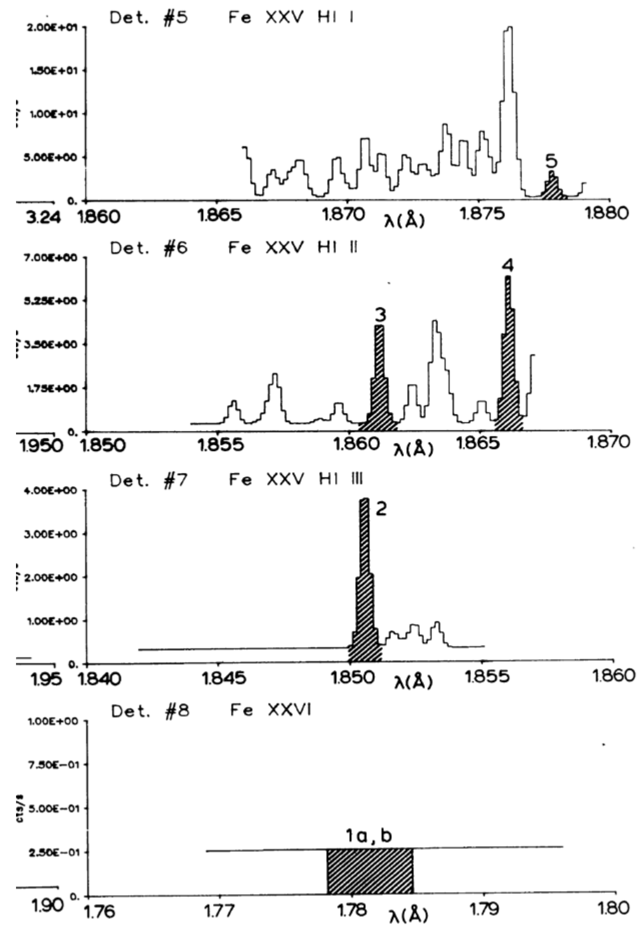
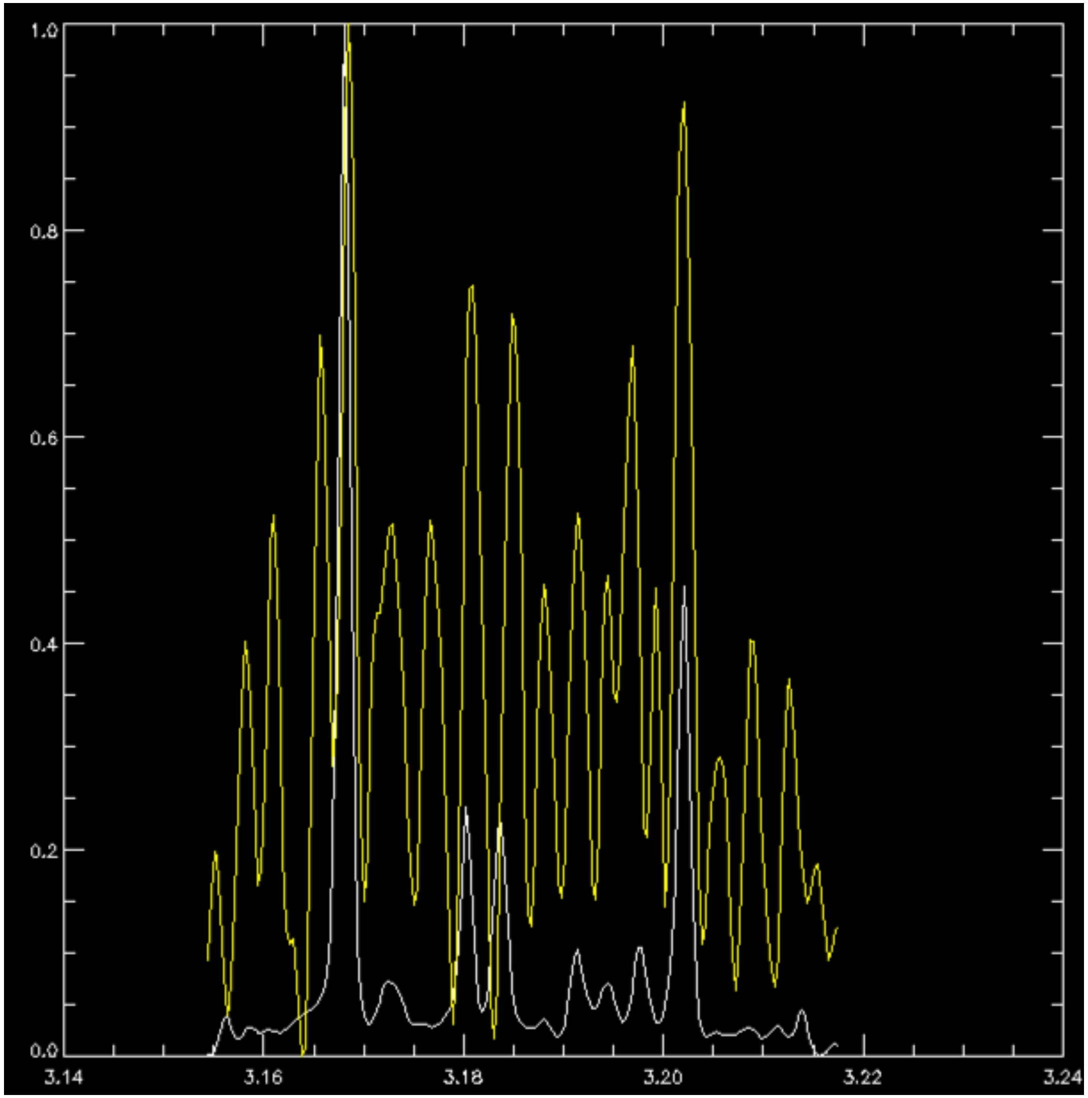


FIG. 7.—Synthetic iron-line spectra illustrating the effect of transient ionization on certain line intensities. Both spectra apply to the same electron temperature, but the lines formed by inner-shell electron impact excitation are enhanced in the lower spectrum.

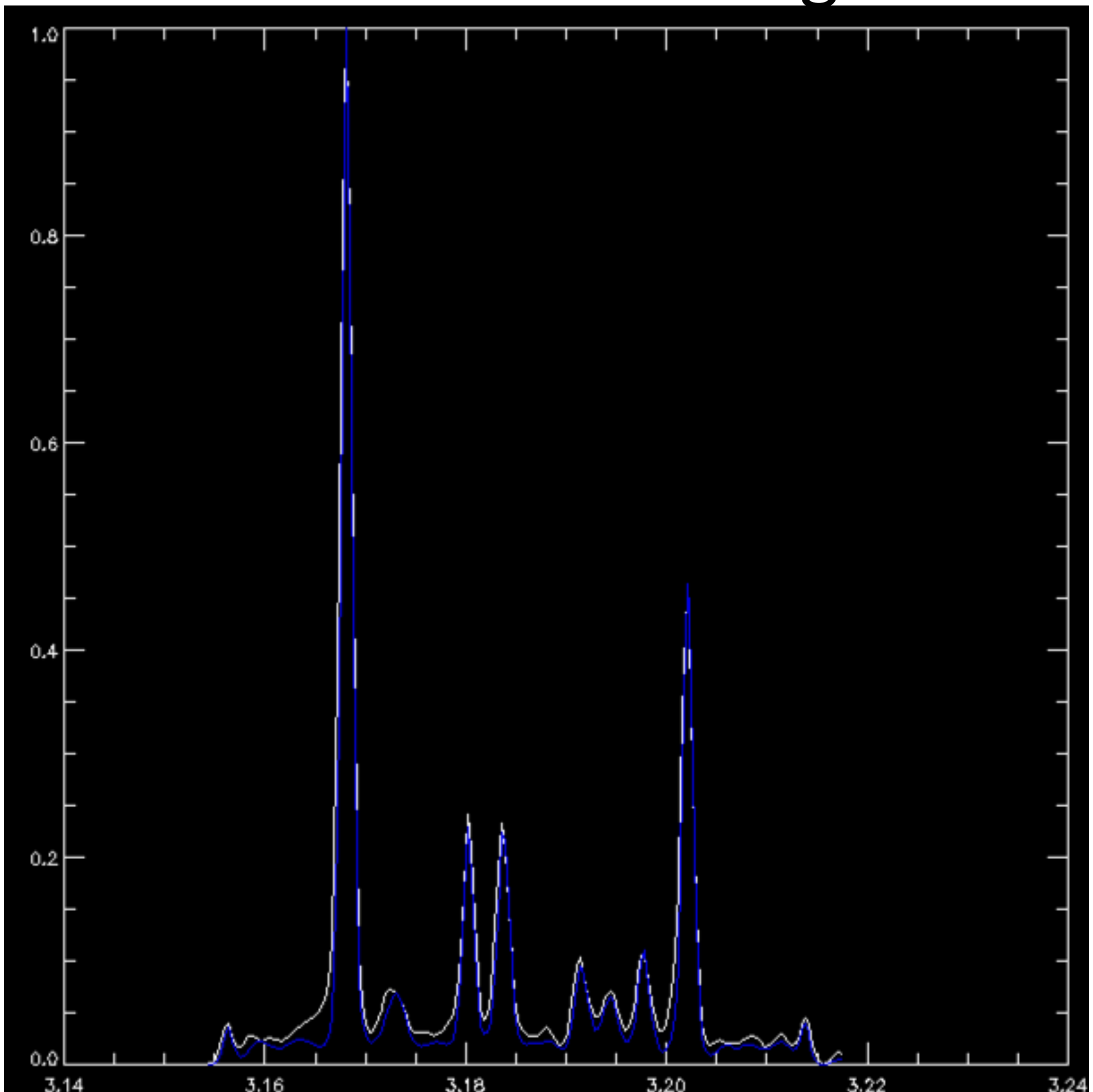


Deconvolved Spectra at different times during the event



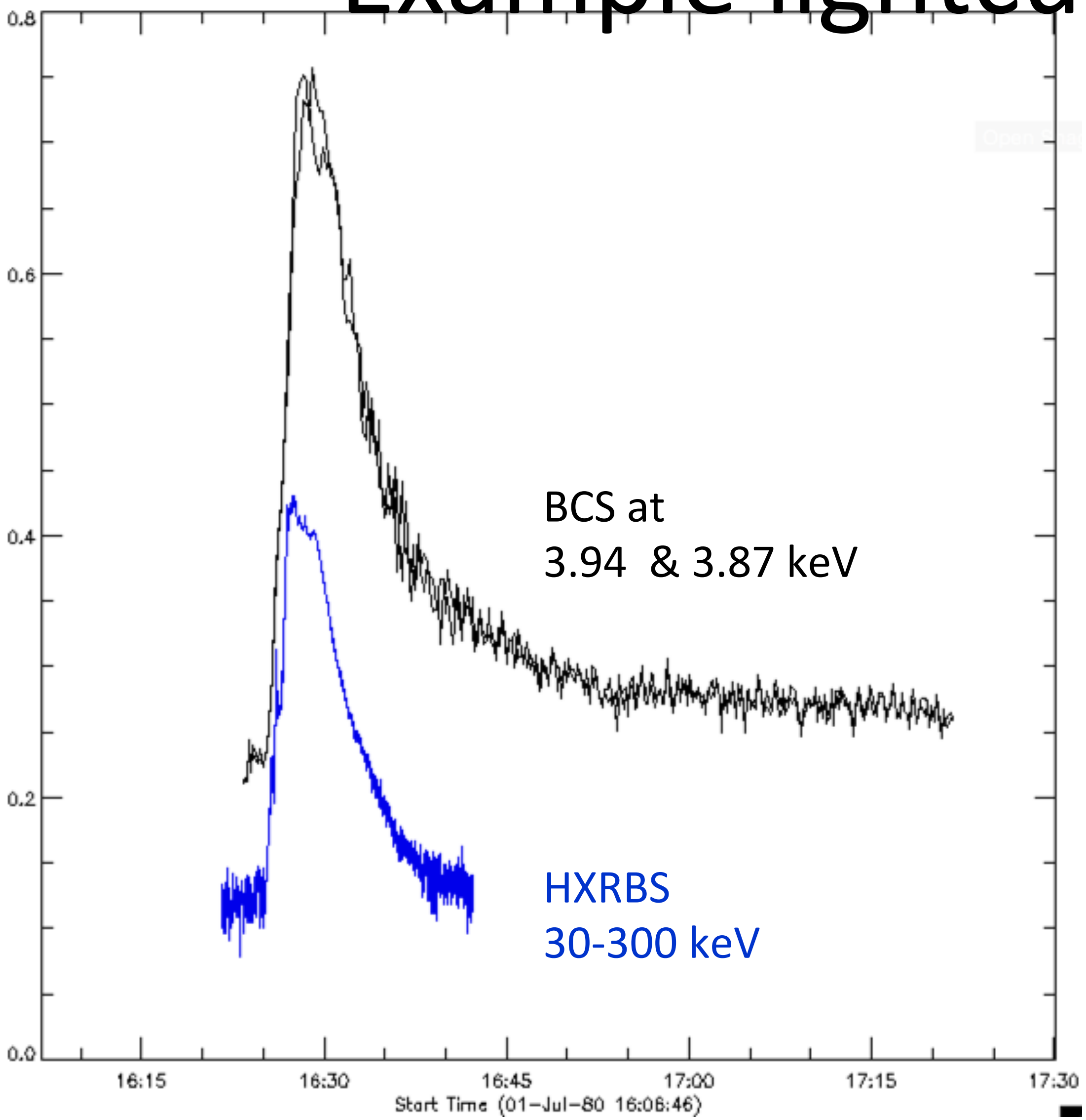
- Yellow: very early rise [0:9]
- White: main phase [10:19]
- Isolated Doppler components seen

Deconvolved normalized spectra at different times during the event



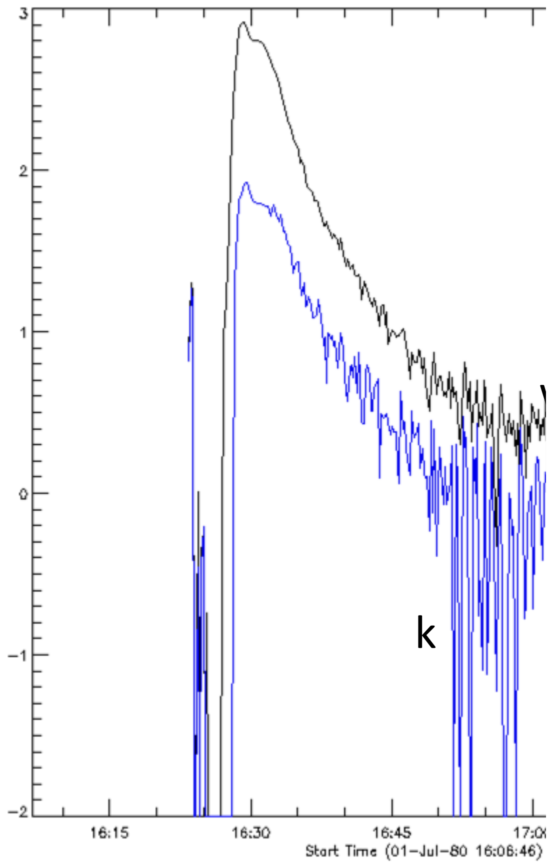
- White: spectra [10:19]
- Blue spectra [20:29]

Example lightcurves

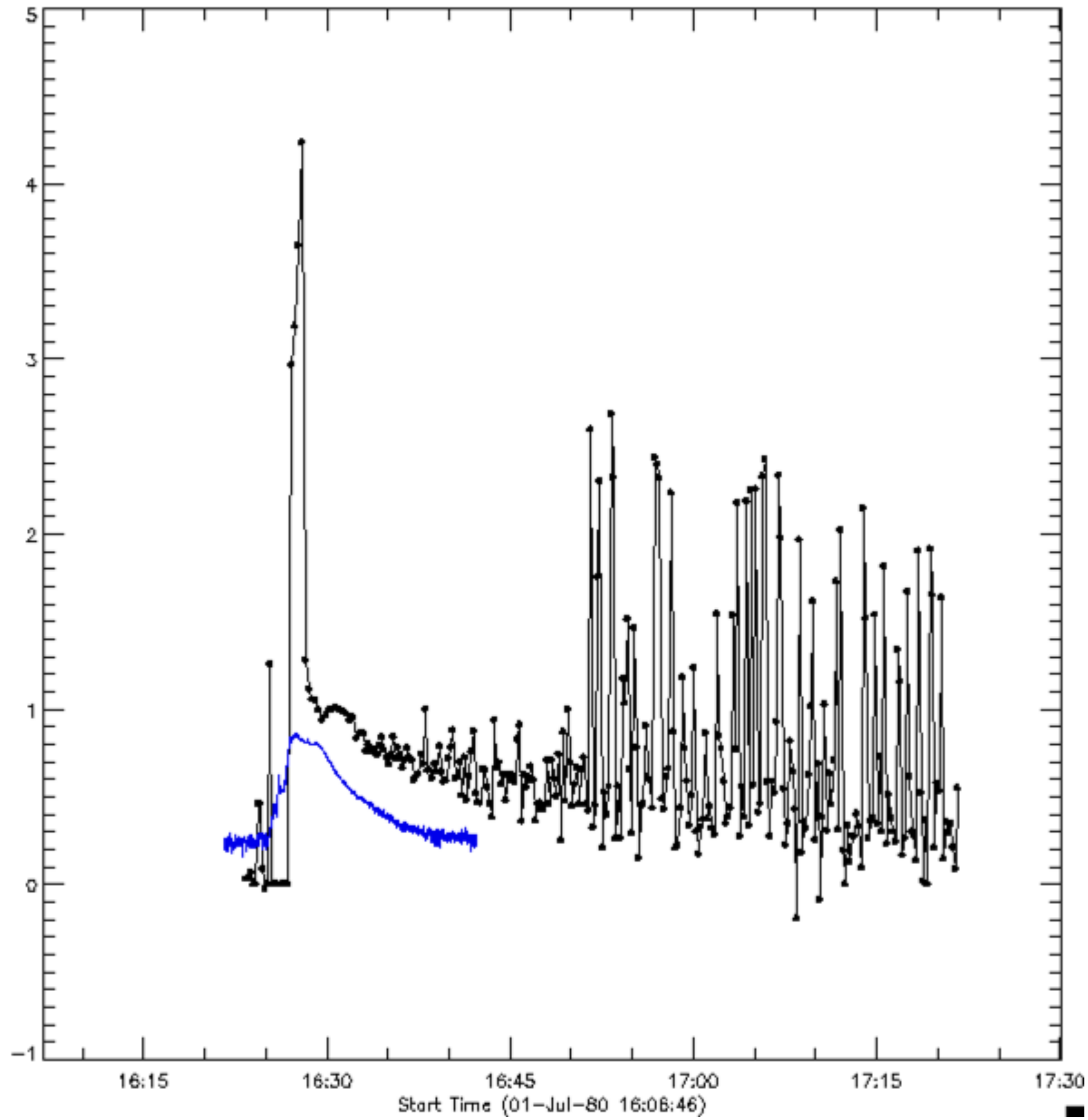


- Excellent coincidence during rise phase
- Left and right BCS chan1 continua overlap but fluctuate!!

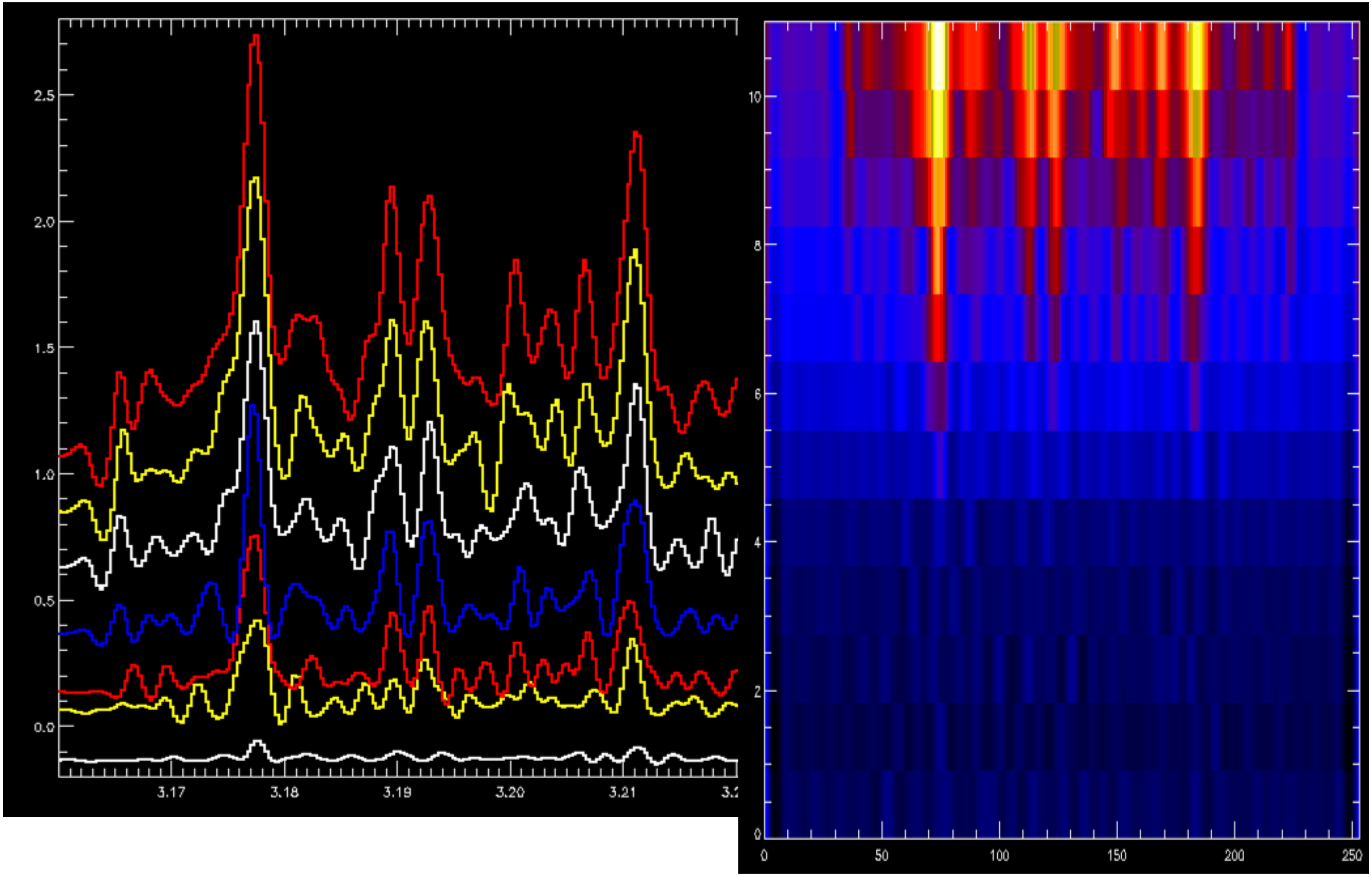
Li

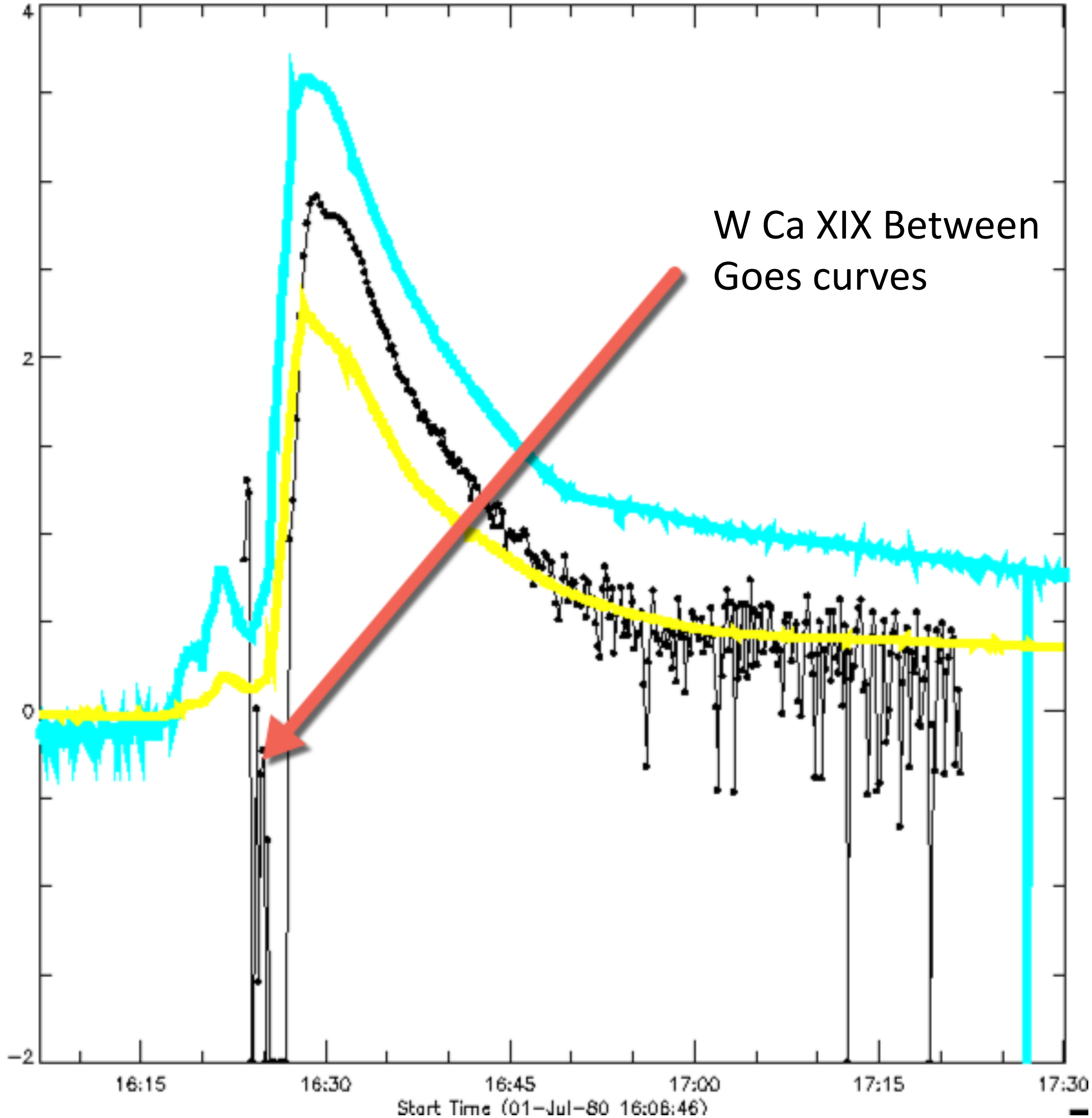

3
2
1
0
−1
−2
16:15
16:30
16:45
17:0
Start Time (01-Jul-80 16:06:46)

k


5
4
3
2
1
0
−1
16:15
16:30
16:45
17:00
17:15
17:30
Start Time (01-Jul-80 16:06:46)

Evolution of deconvolved spectra during the peak




W Ca XIX Between
Goes curves
4
2
0
−2
16:15
16:30
16:45
17:00
17:15
17:30
Start Time (01-Jul-80 16:06:46)

Conclusions

- Our small team is capable & ready to re-establish reduction of SBCS
- We will define time&intensity-dependent wavelenght scale for SBCS
- By comparing many events

  Ca XIX vs GOES 1-8 A the collimator transmission function can be estimated and location of flare within FOV

QUESTIONS

- Are the atomic data base (1990) adequate?
- Can CHIANTI be upgraded? (Kanti Aggarwal ascii database fro collision strengths as well as cross-sections 10^5 entries that he can provide) – now the answer is YES (Thanks Ken)
- Are there people who can help the project???

Hands-on session

- Other flares impulsive ~ 10 different cases
- You suggest what to look for…