Using NDSLIN in EPIC-pn as a proxy for the QPB

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EPIC-pn discarded lines

Number of rejections of a CCD Row or Column (default) due to MIPs (minimum ionizing particle)

- onboard rejection (eFF, FF, LW)

DLI files present in the odf, per CCD

- software (SAS) rejection (eFF, FF, LW, SW, TI, BU)

Value of discarded lines (NDSLIN) integrated over an exposure

- DLIODF column rejection in DLIMAP extension
- DLISAS column rejection in DLIMAP extensión

Since SASv17 discarded lines available per CCD sampled over 20 frames

Aim

Remove Quiescent Particle Background (QPB) in a given science observation: images and spectra

How

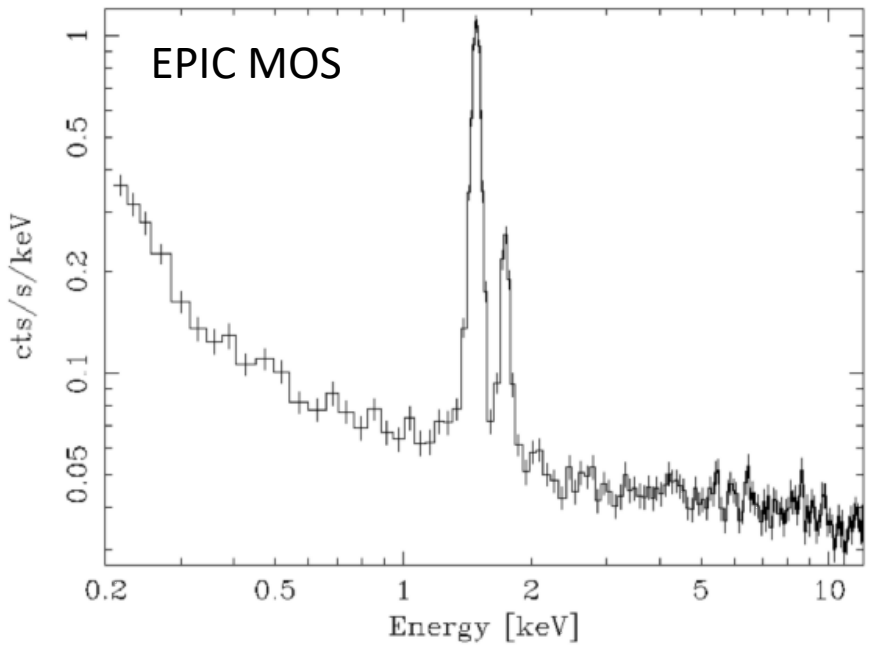
Use full FWC repository for a given EPIC-pn mode (FF)

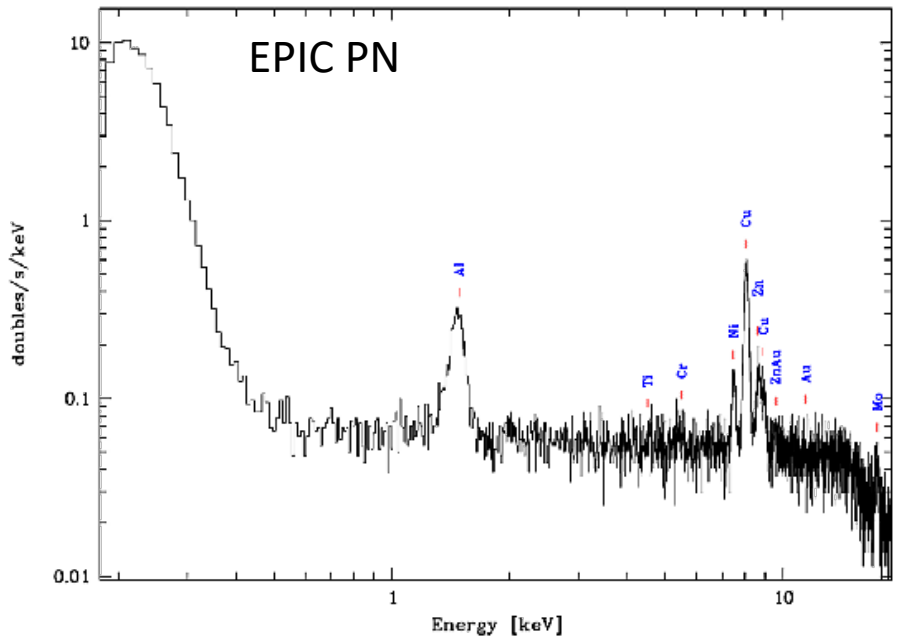
Use NDSLIN as a proxy to estimate the level of quiescent particle induced background rate

What is the Quiescent Particle Background ?

Internal background which is the result of the interaction of High Energy particles (cosmic rays) with the structure surrounding the detectors and the detectors themselves

continuum + instrumental fluorescence





This can be monitored during observations with the filter in the CLOSED position

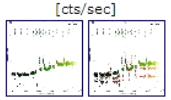
What is Filter Wheel Close (FWC) data ?

Data gathered from calibration observations with the filter wheel in the closed position

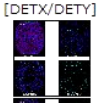
Repository released in September 2006: stacked collections of FWC data available for MOS (FF) and pn (all modes)

The repository is maintained by the SOC, is updated on a yearly basis and reanalyzed continuously with latest SAS version

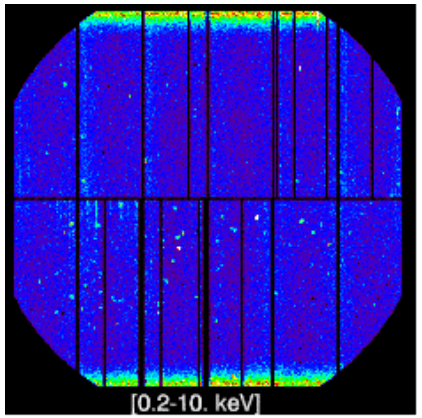
https://www.cosmos.esa.int/web/xmm-newton/filter-closed

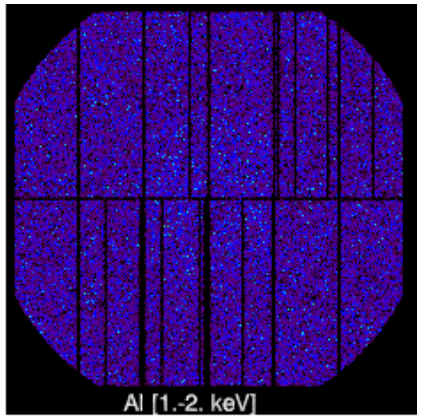
Merged Event List (Rev.266 - Rev.1844)	File Size [Mb]	Total Time [ks]	Image [DETX/DETY]	Light Curve [cts/sec]	Radiation Monitor [cts/sec]
Merged Event File	715	421.1	 (ps file)	 (ps file) (ps file)	 (ps file)

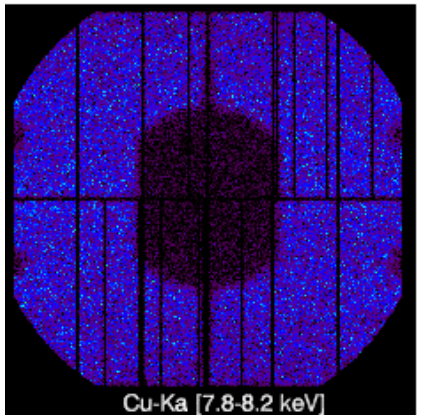
Merged Event List: Merged Filter Wheel Closed event list. No filtering expression has been applied during the generation of the event lists. A column with the revolution number has been added to the event list. The individual event lists that make up the merged file are listed below.
File Size[Mb]: Size of the Merged Filter Wheel Closed event list in units of megabyte.
Total Time[ks]: Duration of the merged Filter Wheel Closed exposures in units of kilosecond.
Image: Combined Filter Wheel Closed filtered image in detector coordinates (DETX, DETY). The filter expression used to create these images is (FLAG==0 && PATTERN <= 4). Four images are shown corresponding to different energy ranges: *Top Left*, energy range 0.2-10 keV; *Top Right*, energy range 1-2 keV; *Bottom Left*, energy range 7.8-8.2 keV; *Bottom Right*, energy range 7.3-7.6 keV. These energy ranges have been chosen to highlight known instrumental spectral features (see the *EPIC background* section of the XMM-Newton User Handbook for more details).
Light Curve: Combined Filter Wheel Closed filtered 100 seconds bin light curves (*green*). The filter expression used to create these light curves is (FLAG==0 && PATTERN <= 4). No energy cut has been applied. The right figure shows the same but includes the light curves corresponding to the high and low energy Radiation Monitor (*red*).
Radiation Monitor: Radiation Monitor 100 seconds bin light curves for high (*red*) and low (*green*) energy over the corresponding revolution. Overimposed is the light curve of the corresponding Filter Wheel Closed observation (*black*).

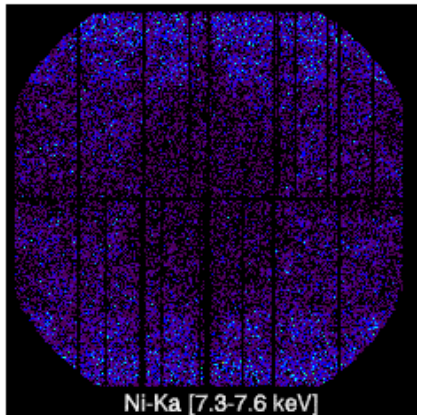
Individual Event List	Time [ks]	Observation Start [UTC Date]	Image [DETX/DETY]	Light Curve [cts/sec]	Radiation Monitor [cts/sec]
0266_0136750301_EPN_U002	28.1	2001-05-22T06:06:51.0			
0363_0112830701_EPN_S005	6.1	2001-12-01T19:37:07.0			
0448_0153750701_EPN_S008	30.5	2002-05-20T19:59:40.0			
0462_0134521601_EPN_S005	23.2	2002-06-18T09:53:21.0			

What we need to know about the Quiescent Particle Background

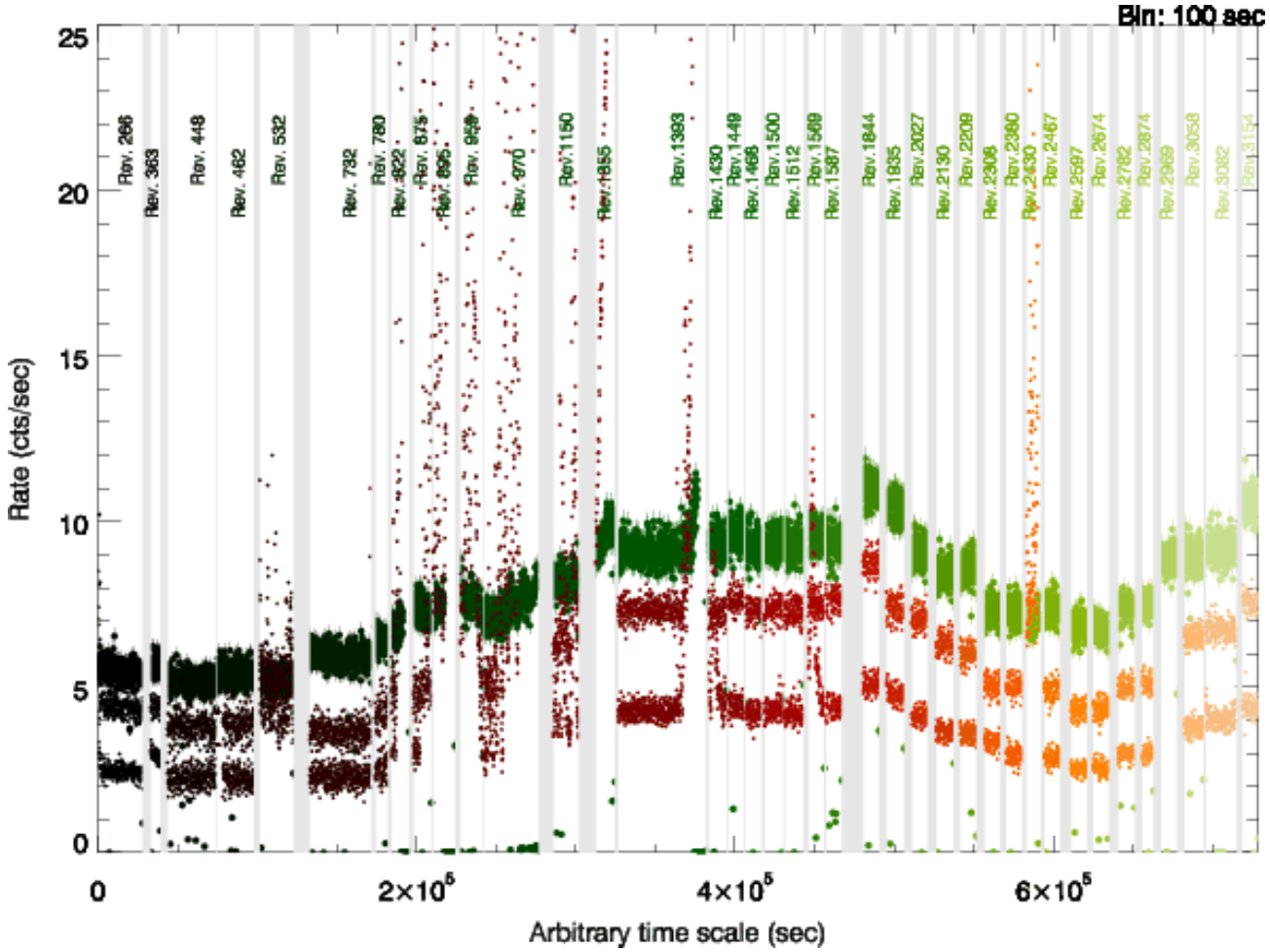








EPIC-pn FF mode Filter Wheel Close data



Internal background is **Spatial** and **Temporal** dependant

How about the spectrum, is it **Spatial** and **Temporal** dependant ?

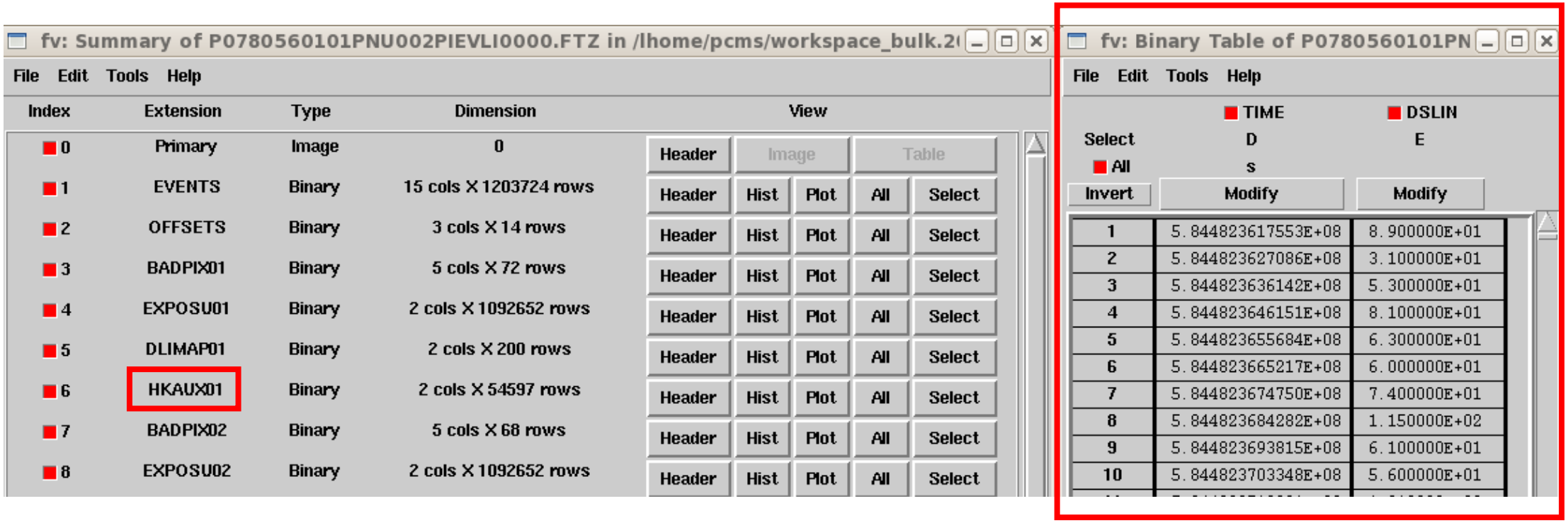
Do NSDLIN correlate with background rates ?

NDSLIN

Based on the analysis of 552 **EPIC-pn** science observations taken in **Full Frame** (FF) mode (analysis with SASv17). The observations are randomly choosen over 16 years (2002-2018).

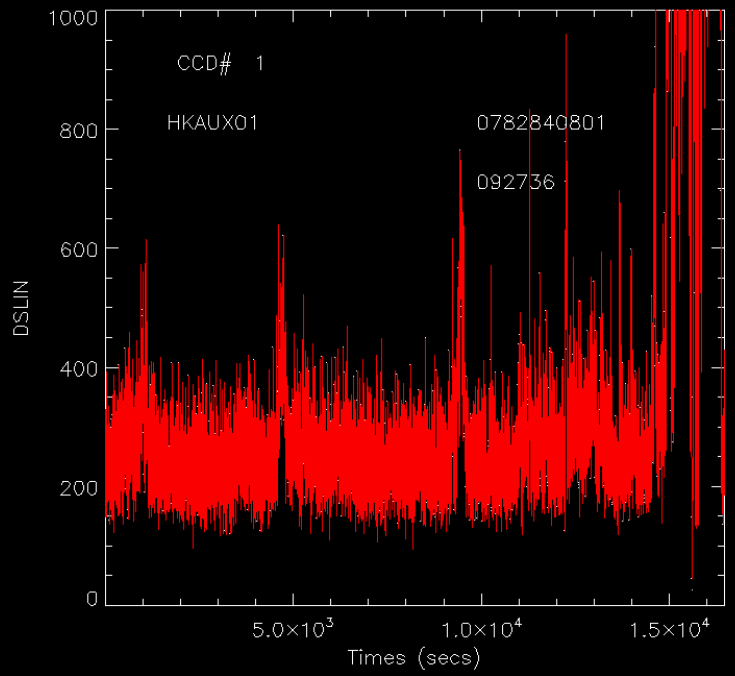
EPIC-pn Event file including NDSLIN information

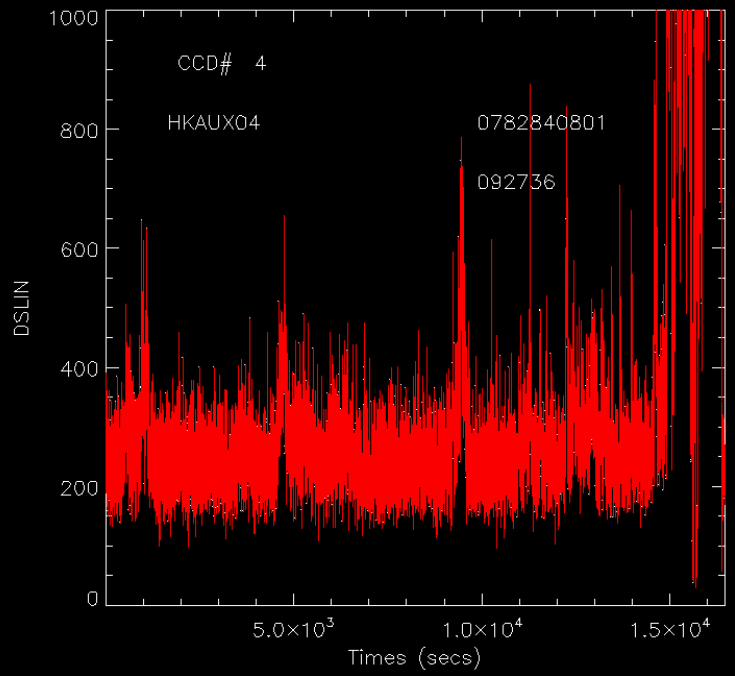
HKAUX01

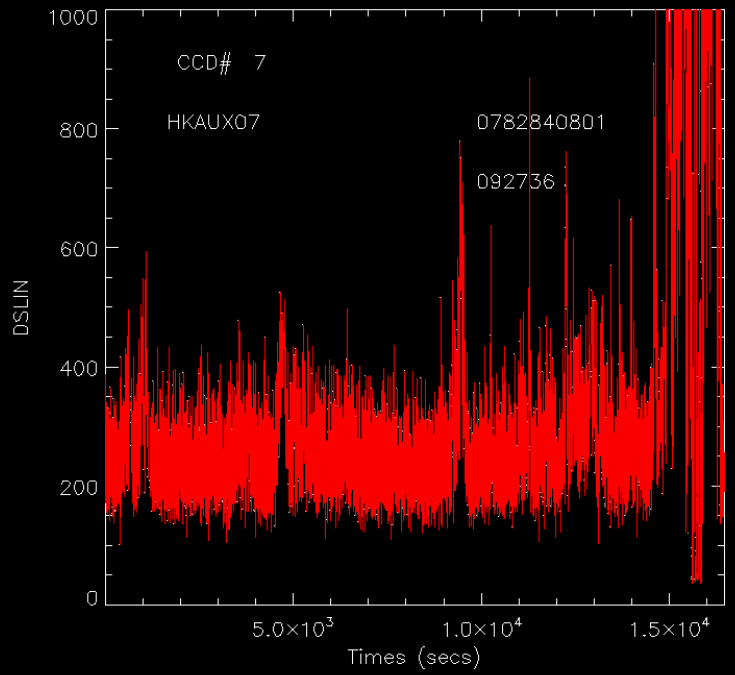


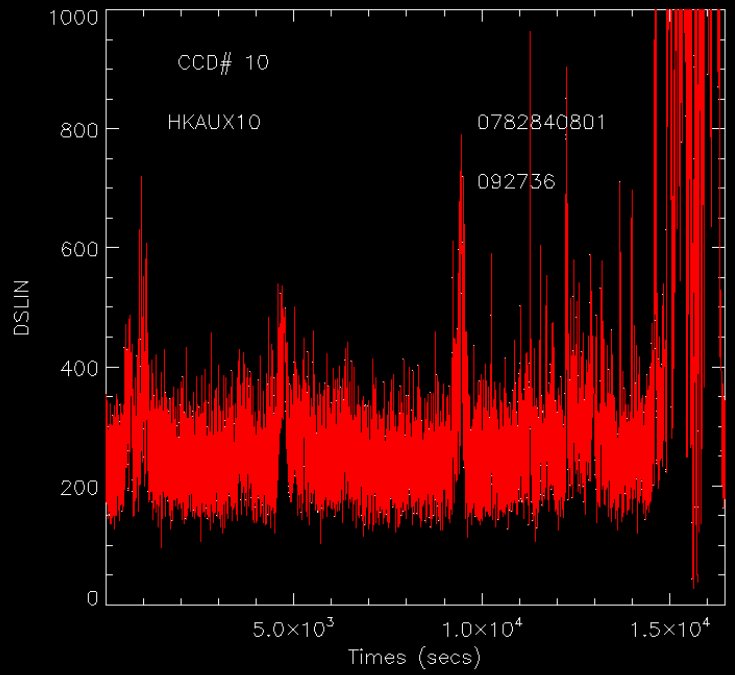
12 extensions **HKAUX01-HKAUX12** (one per CCD)
DSLIN values stored per CCD, but equal within the CCDs in a quadrant

One value every 20xFrametime, ~1.46 secs (FF frametime 73 msec)







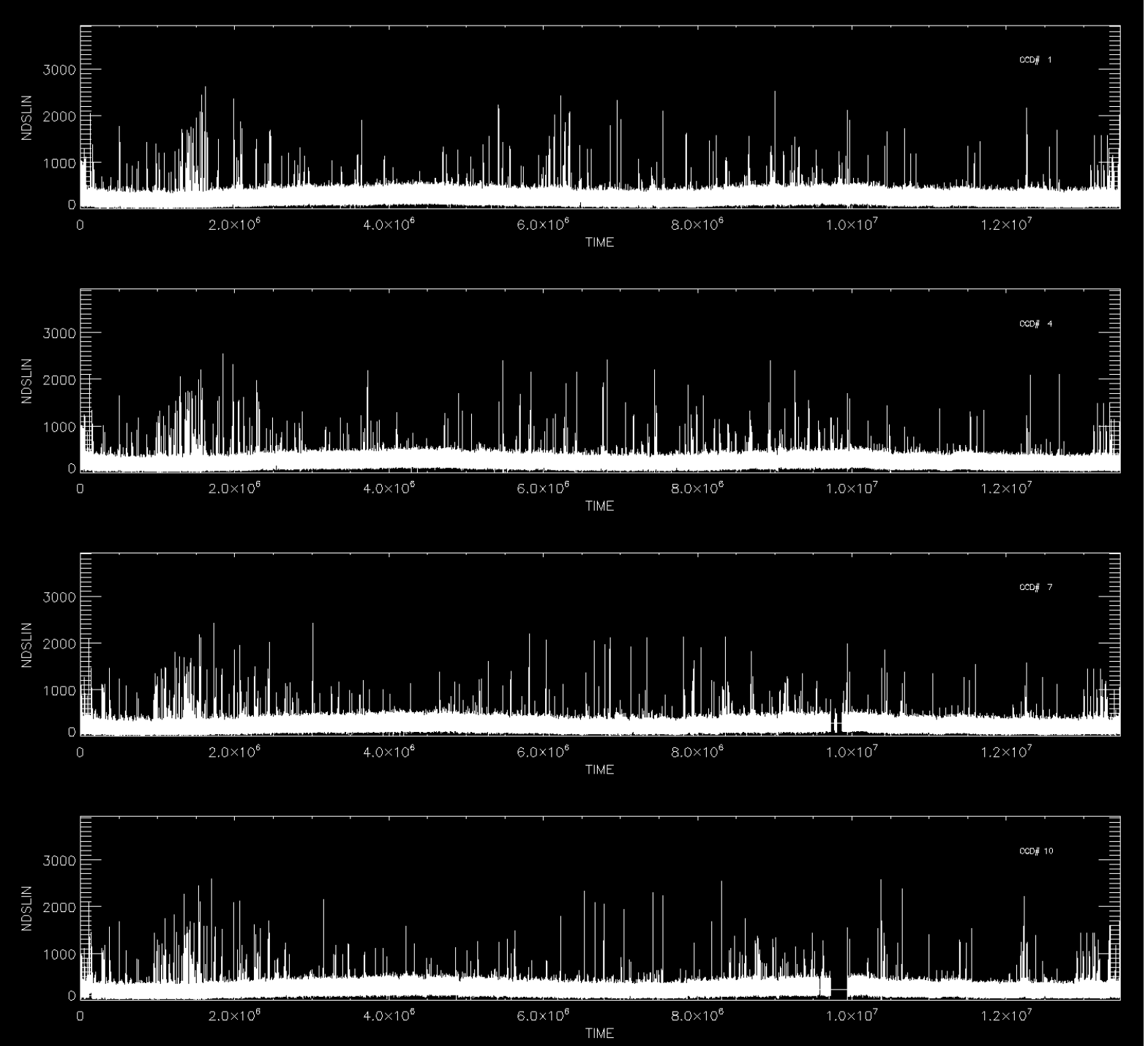


NDSLIN vs Time
for one obervation

Four quadrants represented
(CCD#1, CCD#4, CCD#7 and CCD#10)

Obsid. 0782840801

Some Time values set to **Null**



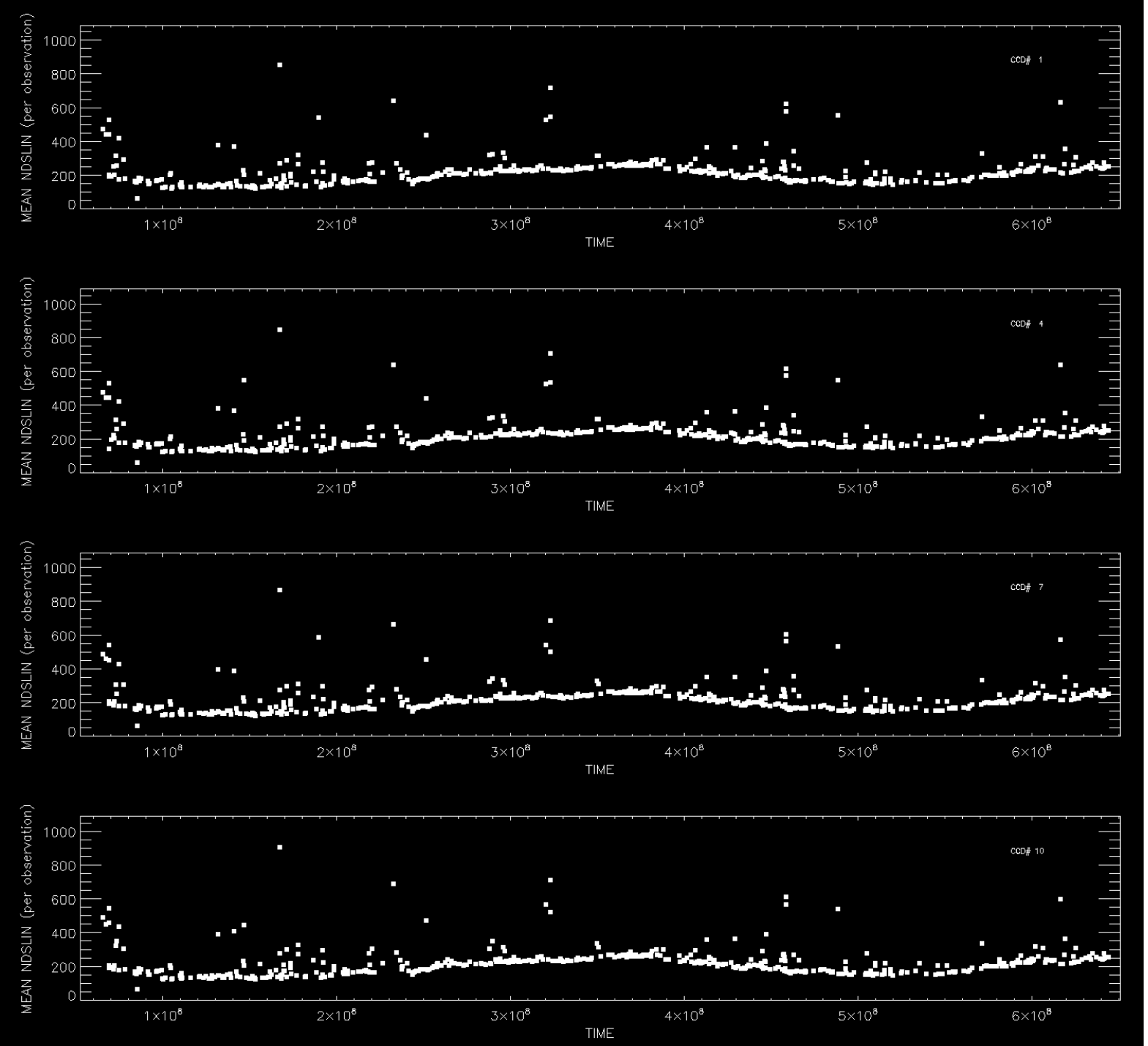
NDSLIN vs Time for all obervations

Four quadrants represented
(CCD#1, CCD#4, CCD#7 and CCD#10)

Covered Period:

Rev. 400 – 2002-02-13

Rev. 3369 – 2018-05-02



Mean NDSLIN vs Time

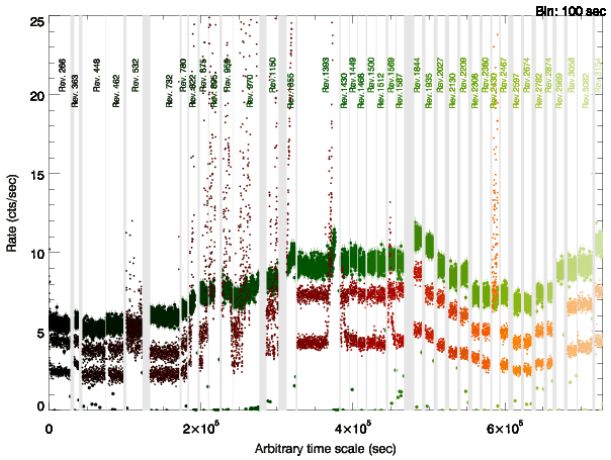
Four quadrants represented
(CCD#1, CCD#4, CCD#7 and CCD#10)

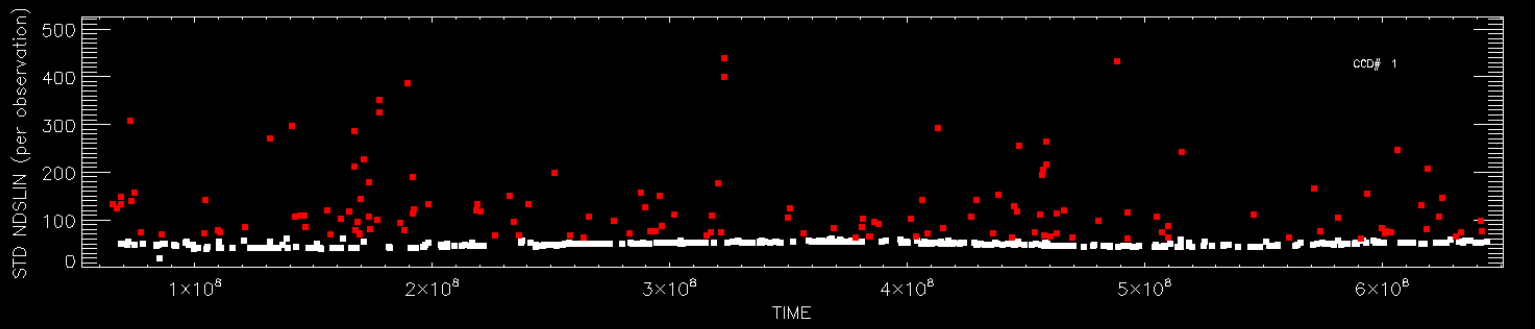
Covered Period:

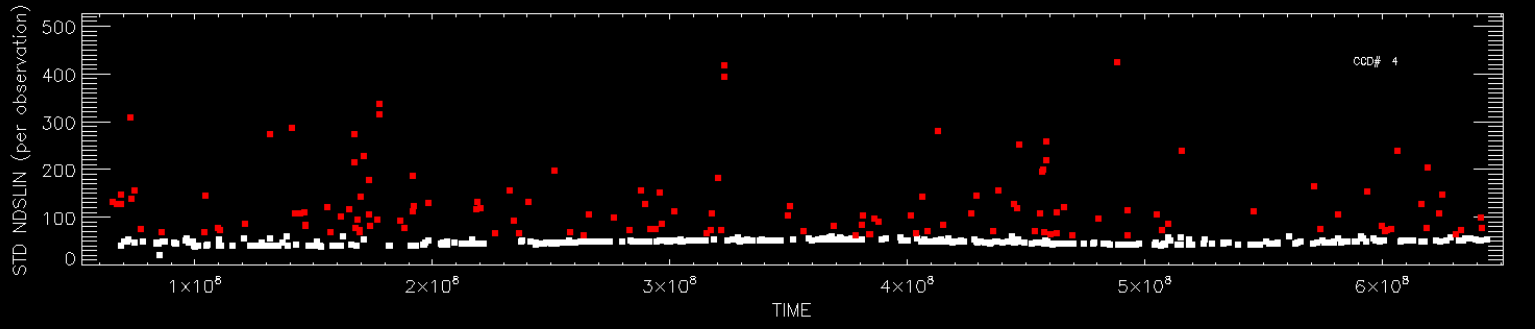
Rev. 400 – 2002-02-13

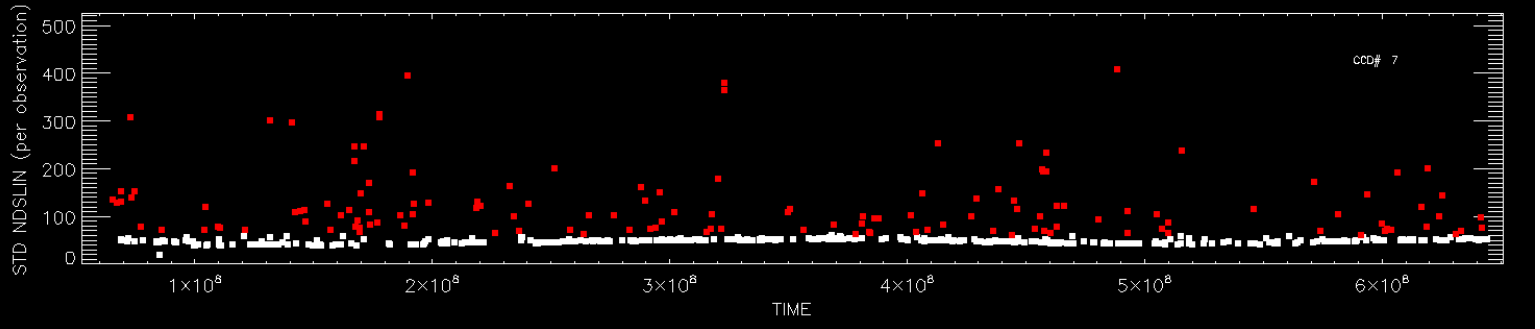
Rev. 3369 – 2018-05-02

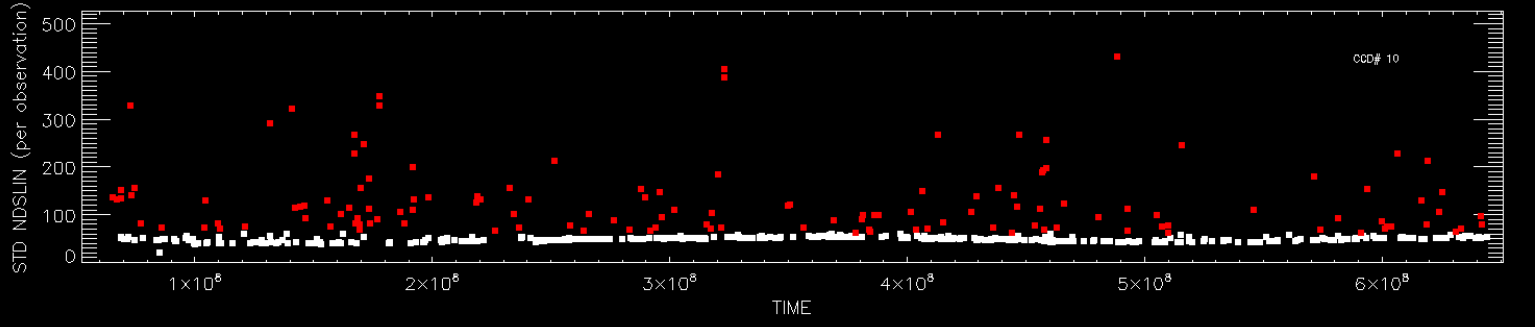
Mean value across each observation











STD NDSLIN vs Time

Four quadrants represented
(CCD#1, CCD#4, CCD#7 and CCD#10)

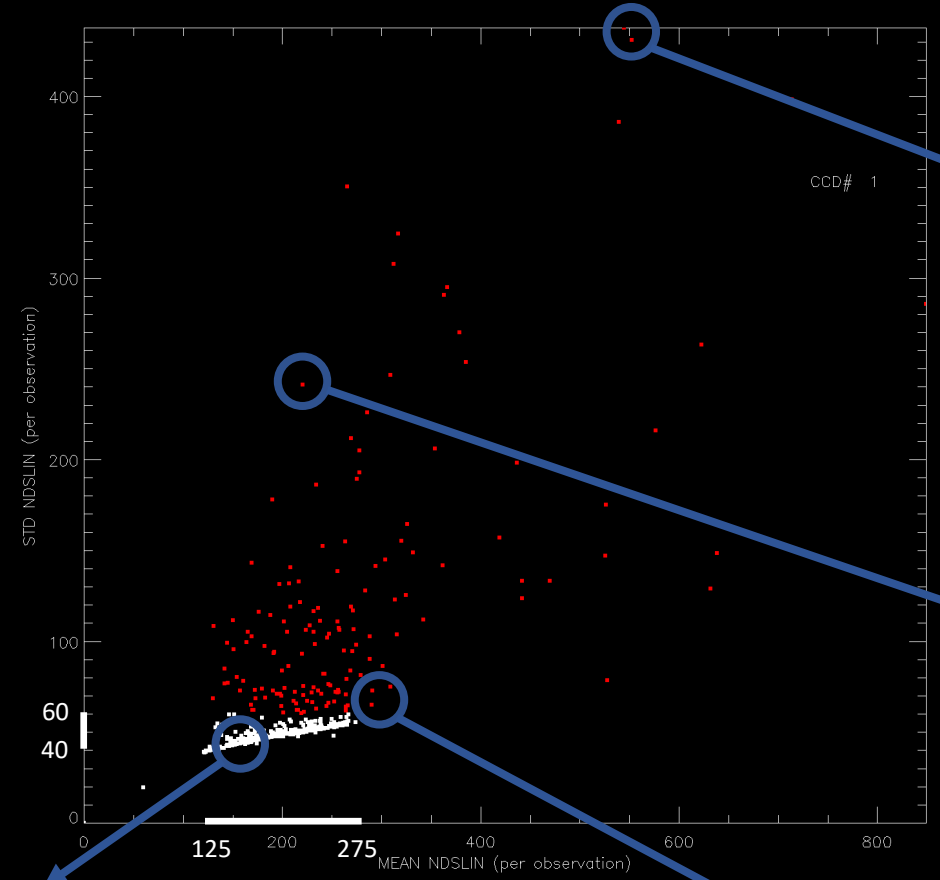
Covered Period:

Rev. 400 – 2002-02-13

Rev. 3369 – 2018-05-02

STD within each observation
(red: STD > 60)

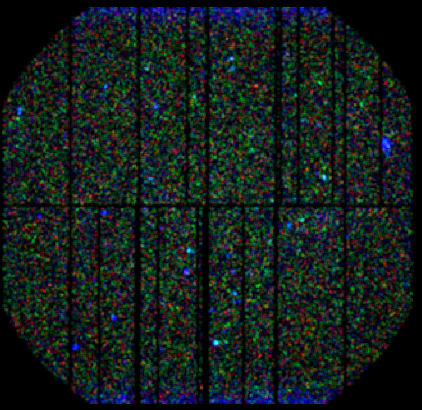
Mean vs STD NDSLIN

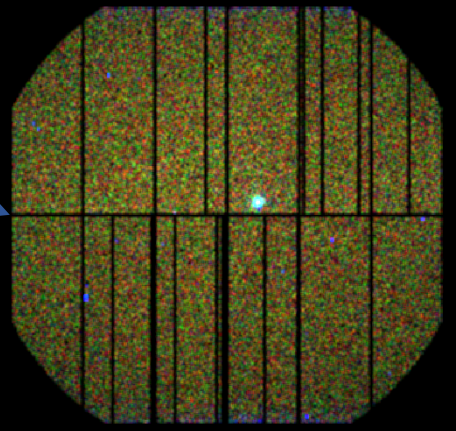


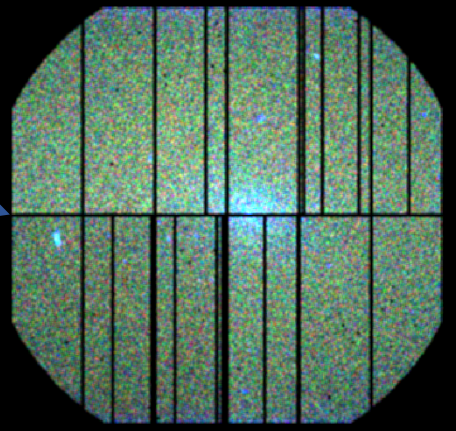
Image

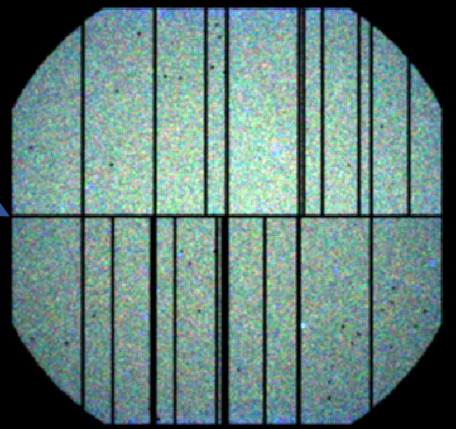
Red: 8.5-12 keV Green: 2-6 keV Blue: 0.2-2 keV

No BKG Filtered

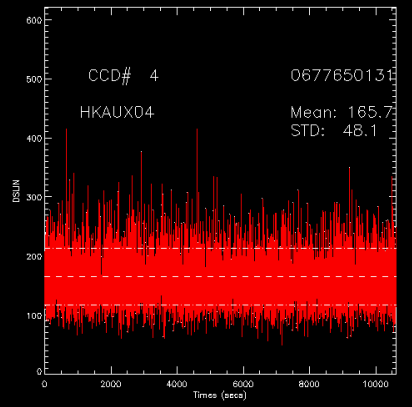


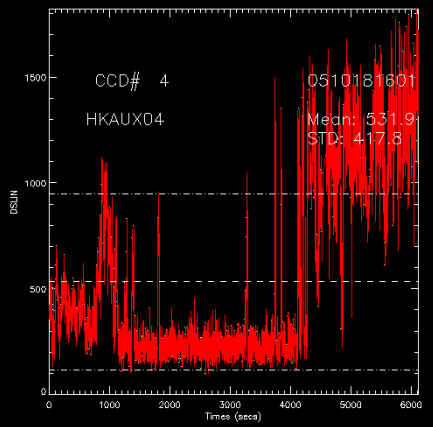


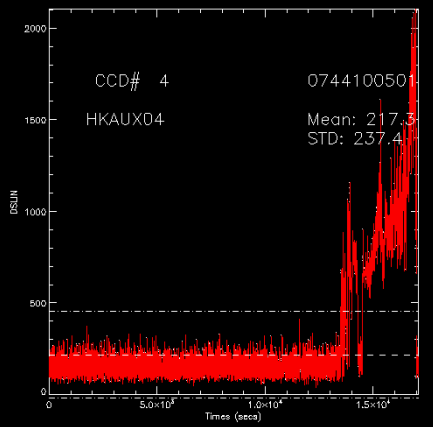


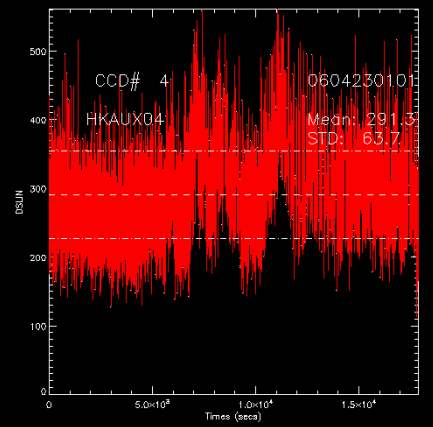


NDSLIN vs Time



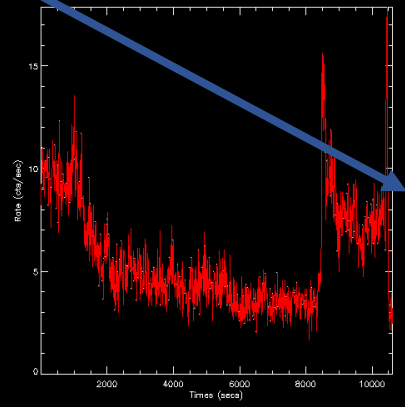


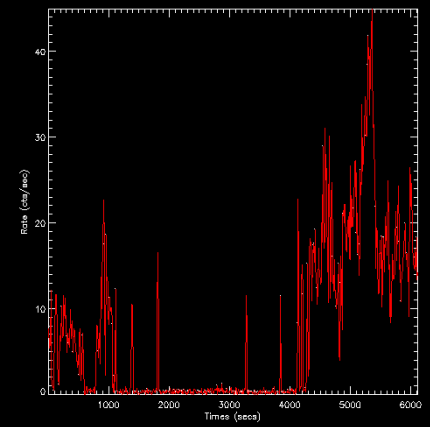


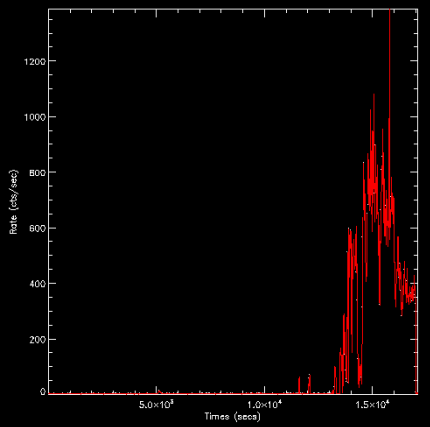


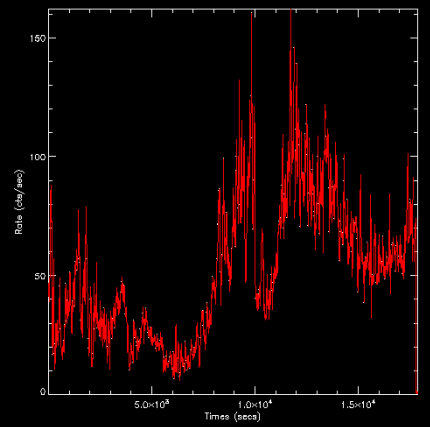
BKG Rate vs Time

Full FOV, 0.5-7.5 keV



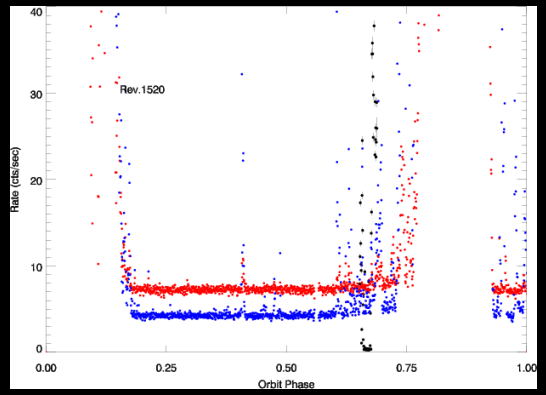


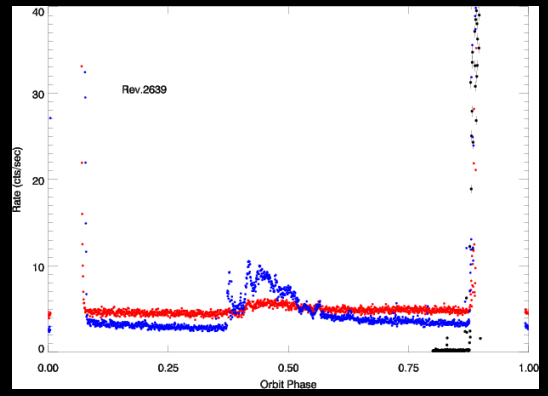


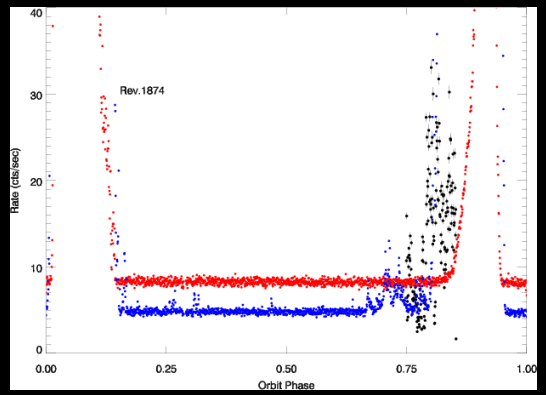


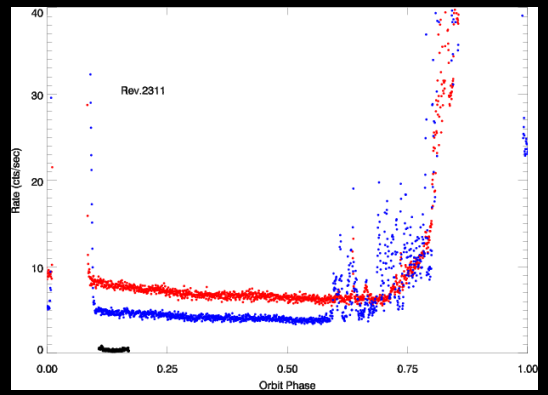
RADMON

Red: High Energy ; Blue: Low Energy





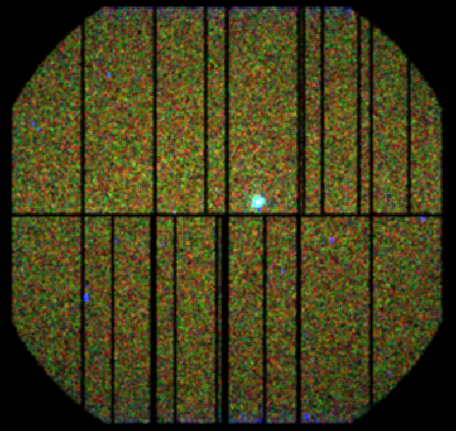


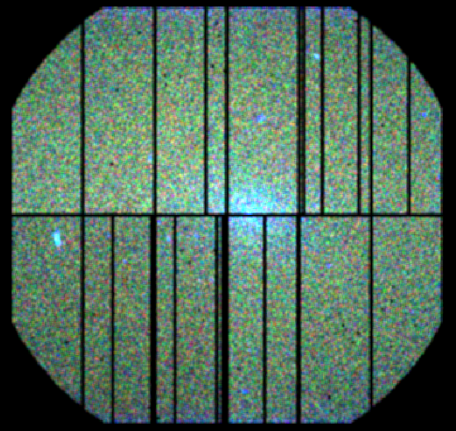


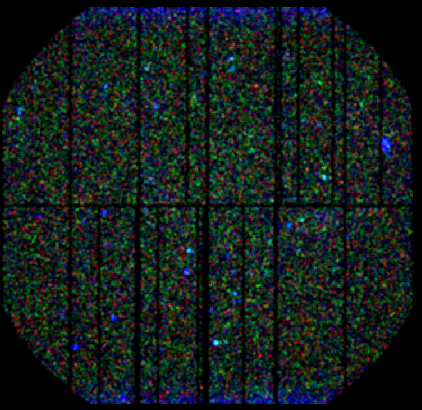
Image

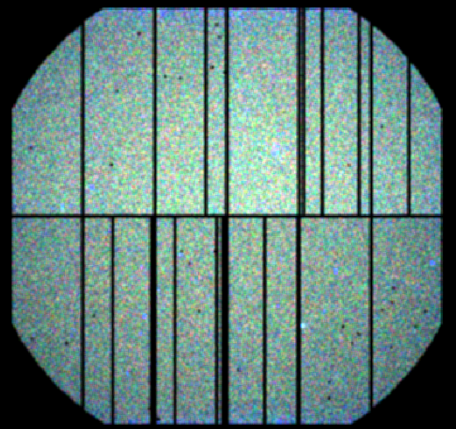
Red: 8.5-12 keV Green: 2-6 keV Blue: 0.2-2 keV

No BKG Filtered

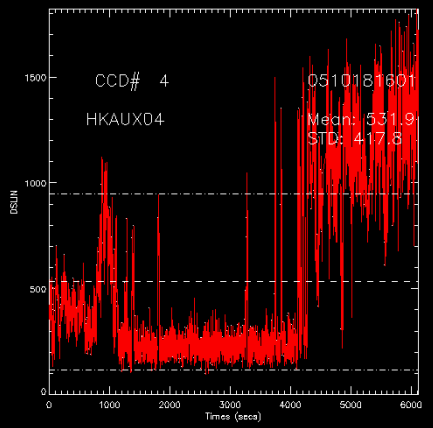


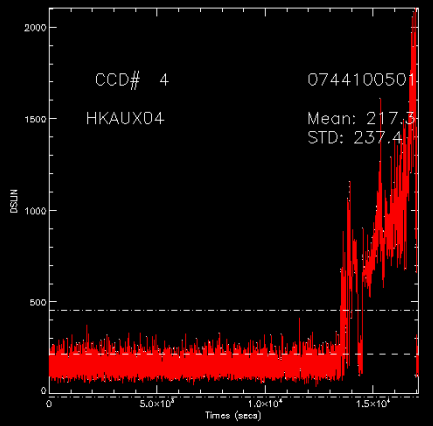


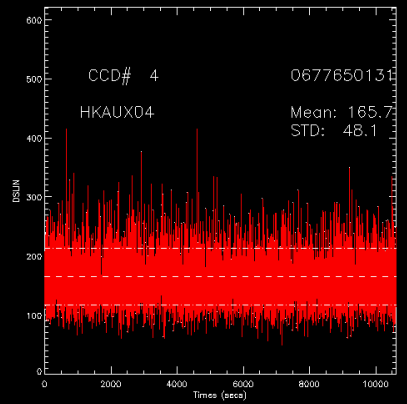


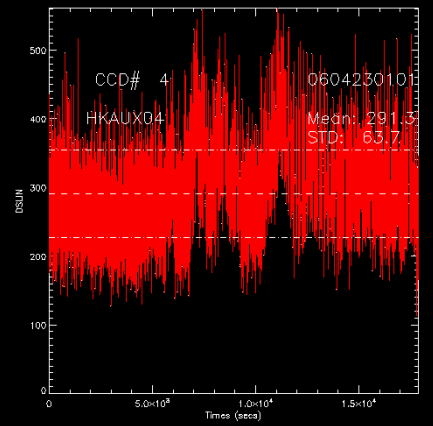


NDSLIN vs Time



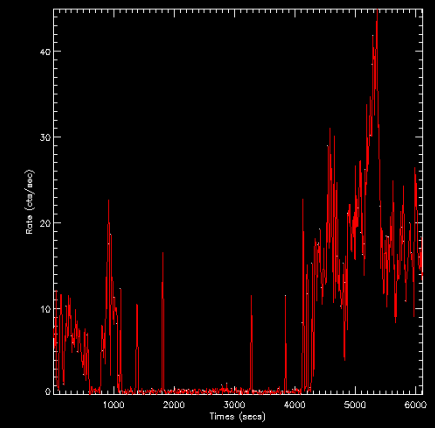


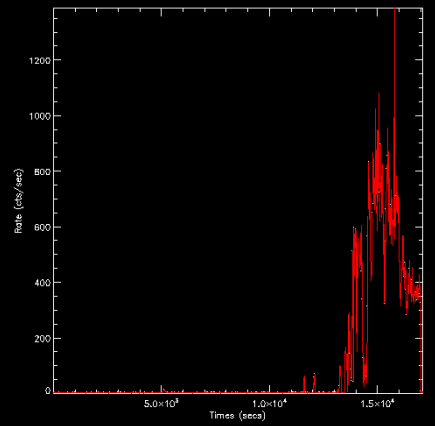


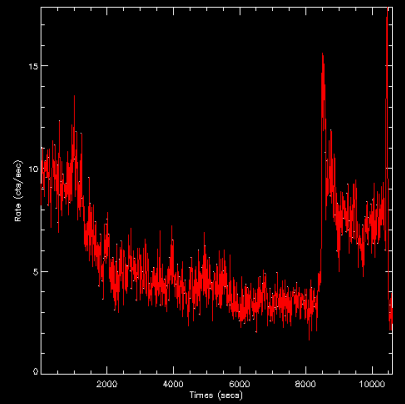


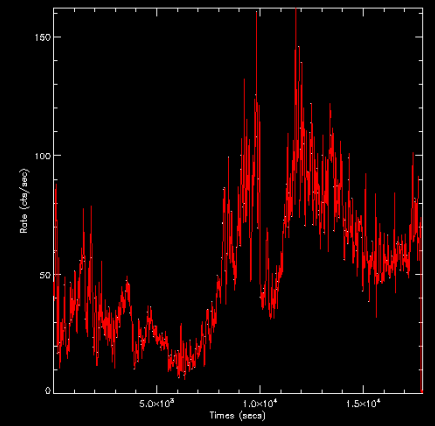
BKG Rate vs Time

Full FOV, 0.5-7.5 keV









NDSLIN as a proxy for instrumental noise

Analysis of EPIC-pn FF FWC Data

40 EPIC-pn FF FWC exposures

2001-2018

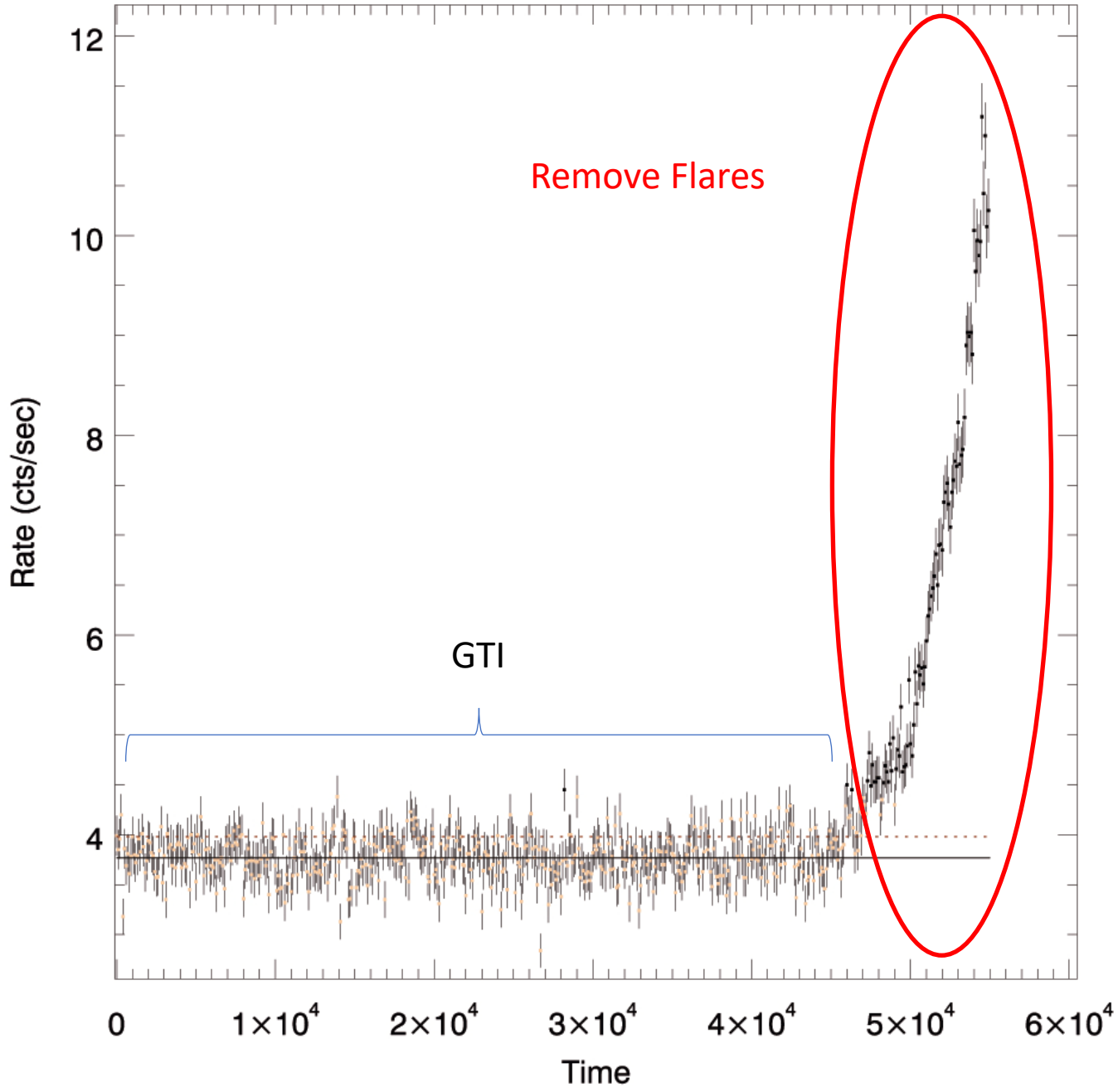
SASv17

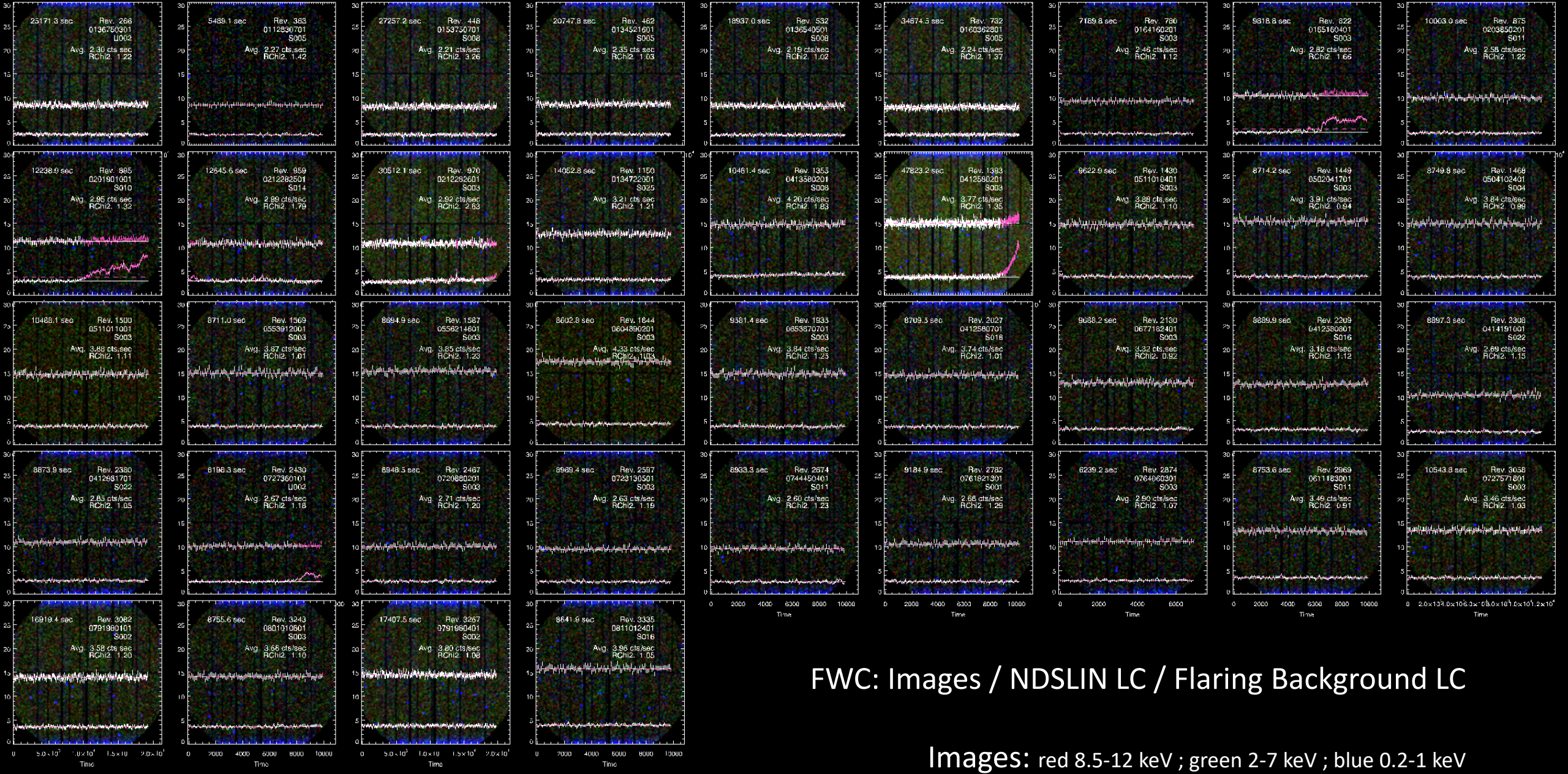
Background Filtering of FWC Data (GTI)

#XMMEA_EP && (PI in [200:10000] && PATTERN==0)

100 sec bin Lightcurve

Derive Mean Rate and Error from fit to GTI Rates





FWC: Images / NDSLIN LC / Flaring Background LC

Images: red 8.5-12 keV ; green 2-7 keV ; blue 0.2-1 keV

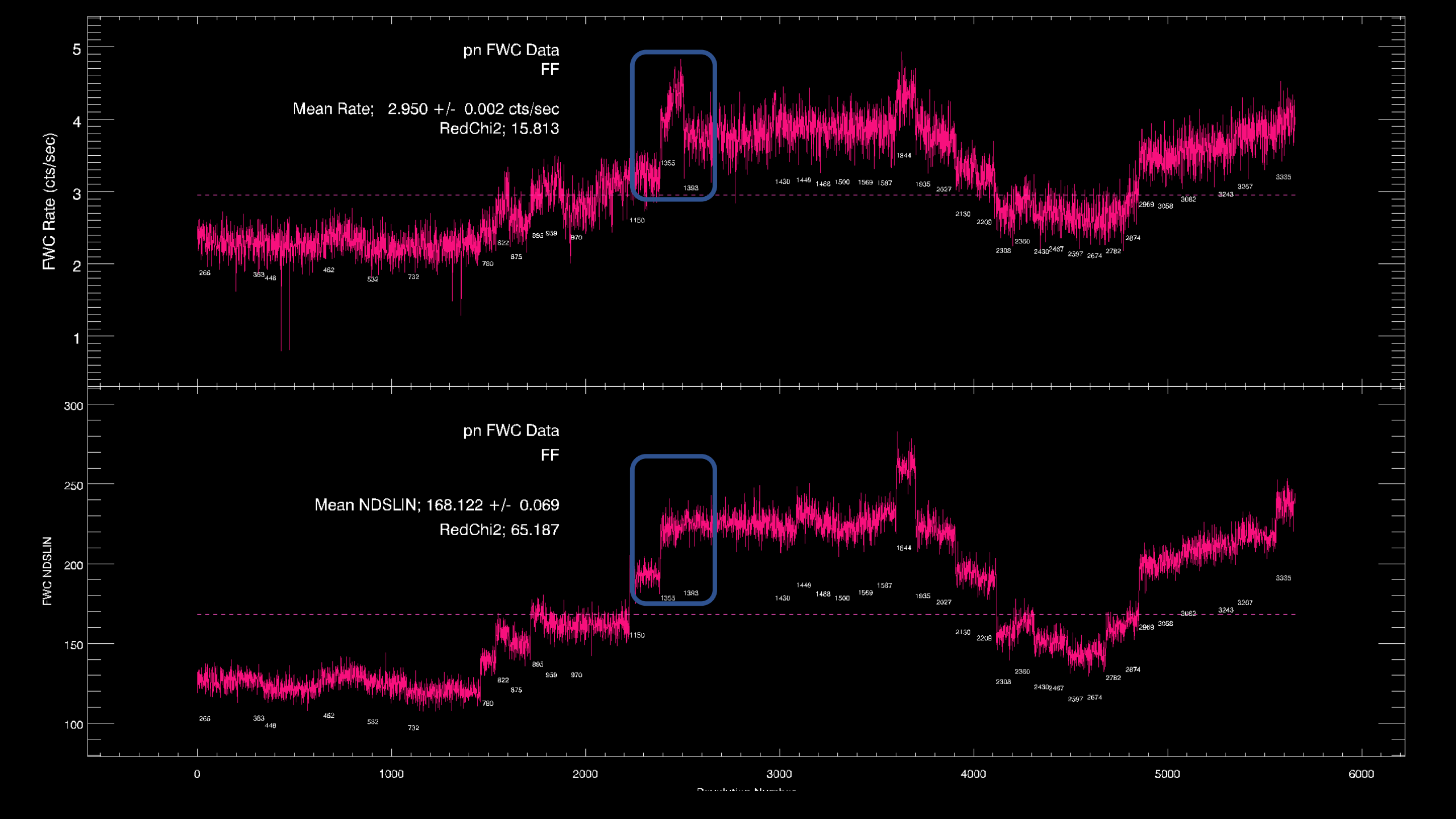
NDSLIN LC: rebin to match FL Background LC

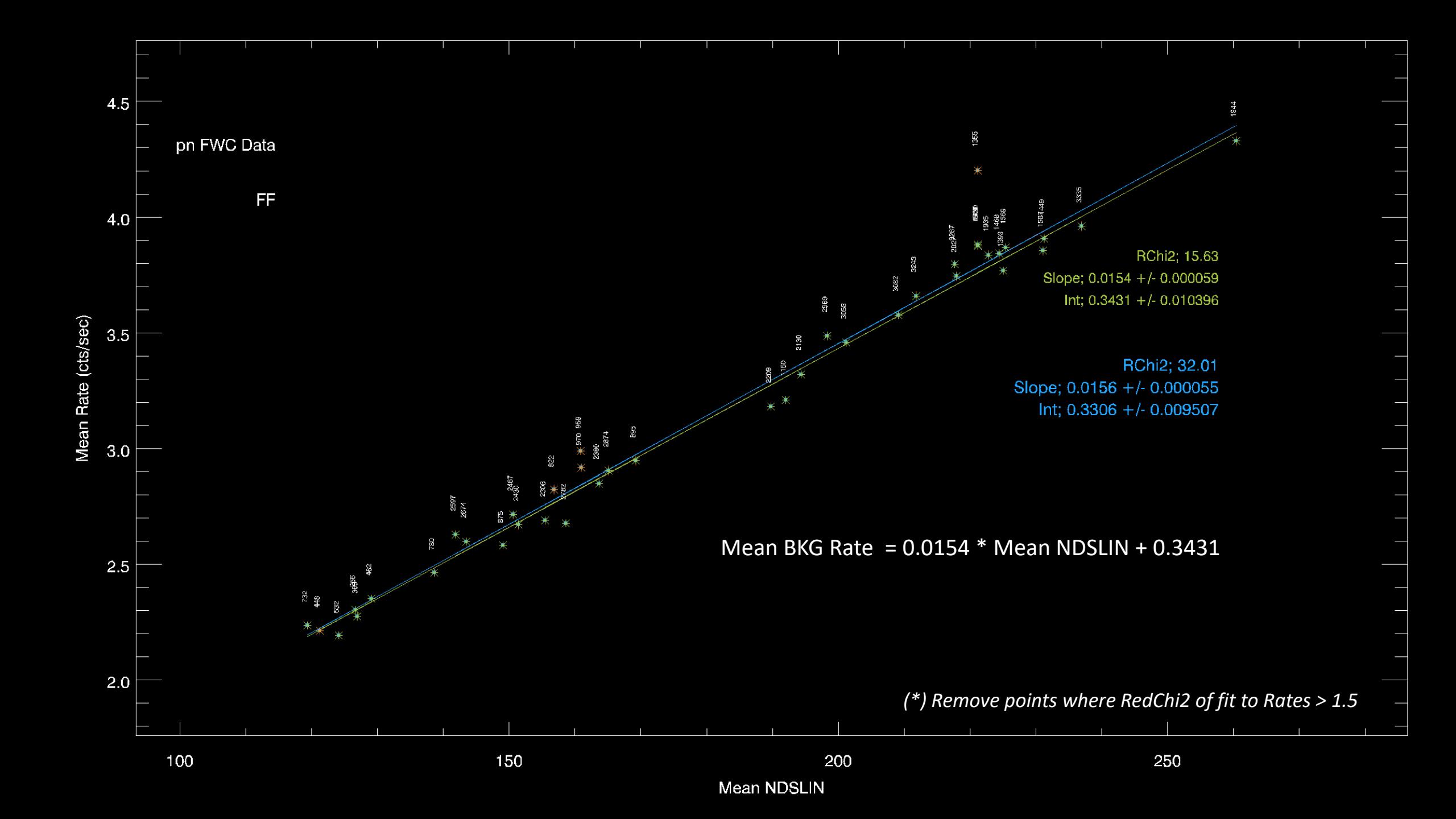
FL Background LC: 100 sec bin, XMM_EP && 0.2-10. keV

For each exposure:

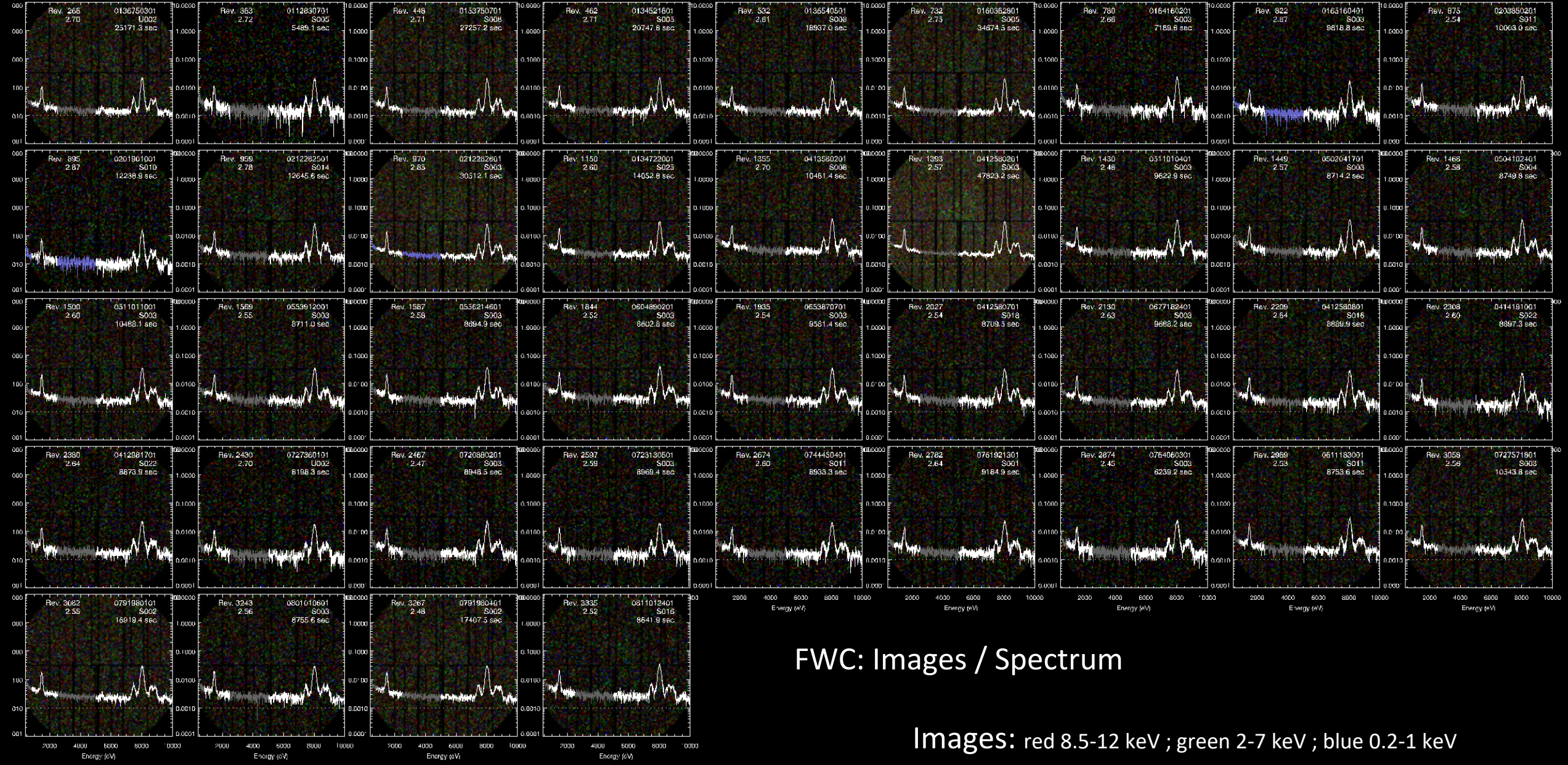
Derive Mean Rate and Error from fit to GTI BKG Rates

Derive Mean NDSLIN and Error from fit to GTI BKG Rates


pn FWC Data
FF
Mean Rate; 2.950 +/- 0.002 cts/sec
RedChi2; 15.813
FWC Rate (cts/sec)
pn FWC Data
FF
Mean NDSLIN; 168.122 +/- 0.069
RedChi2; 65.187
FWC NDSLIN
Revolution Number


pn FWC Data
FF
Mean Rate (cts/sec)
Mean NDSLIN
4.5
4.0
3.5
3.0
2.5
2.0
100
150
200
250
RChi2; 15.63
Slope; 0.0154 +/- 0.000059
Int; 0.3431 +/- 0.010396
RChi2; 32.01
Slope; 0.0156 +/- 0.000055
Int; 0.3306 +/- 0.009507
Mean BKG Rate = 0.0154 * Mean NDSLIN + 0.3431
(*) Remove points where RedChi2 of fit to Rates > 1.5

Is the FWC spectrum stable with time ?



FWC: Images / Spectrum

Images: red 8.5-12 keV ; green 2-7 keV ; blue 0.2-1 keV

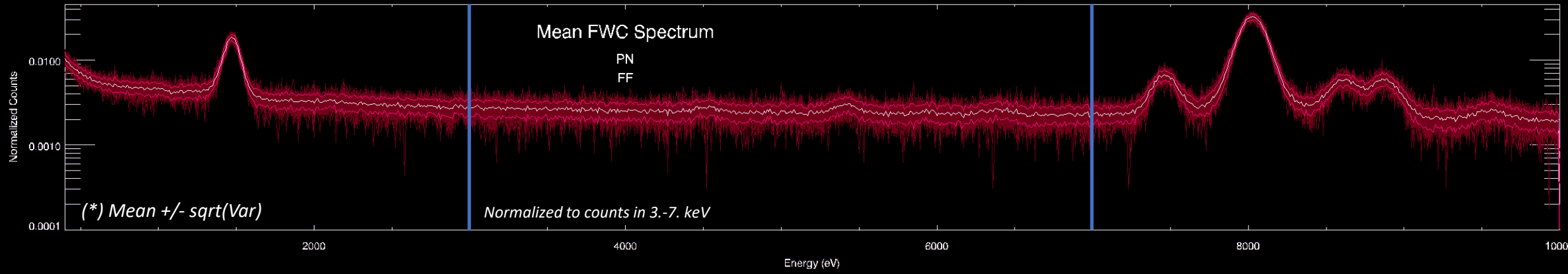
FWC Spectra: 0.4-10 keV in 10 eV channels

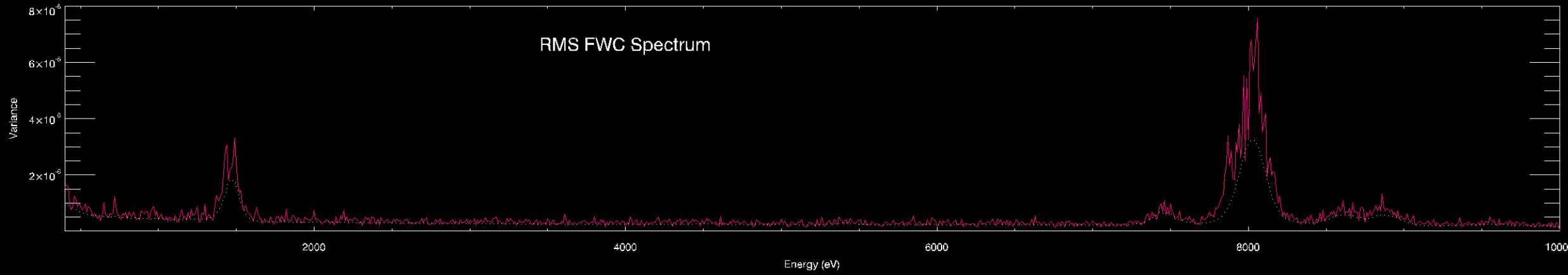
FLAG==0 and pattern <= 4

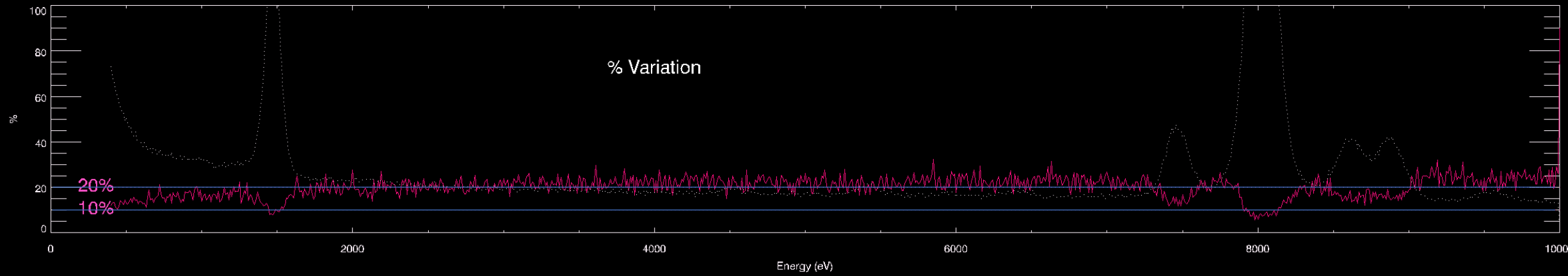
Each spectra normalized to exposure time

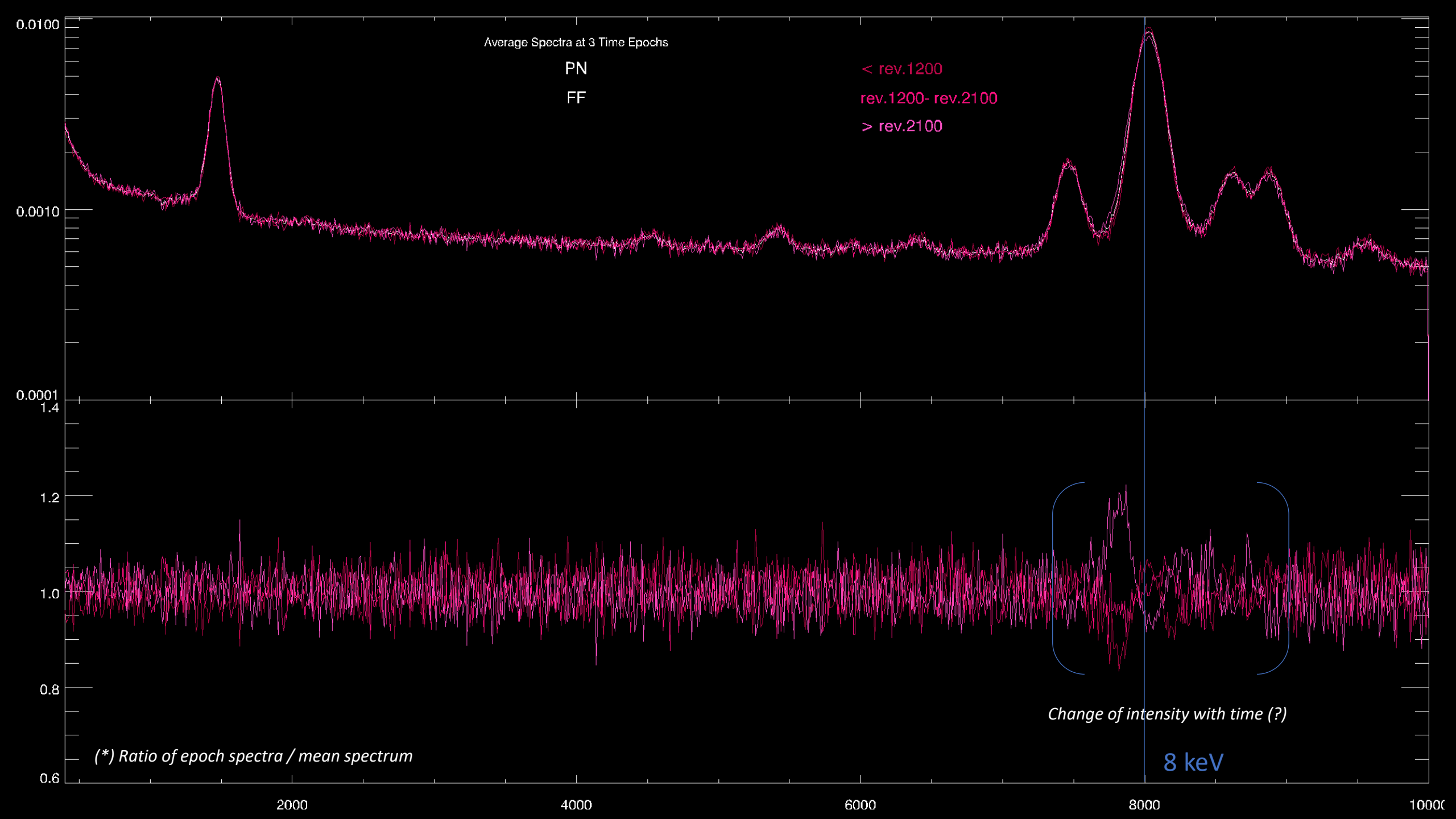
For each exposure:

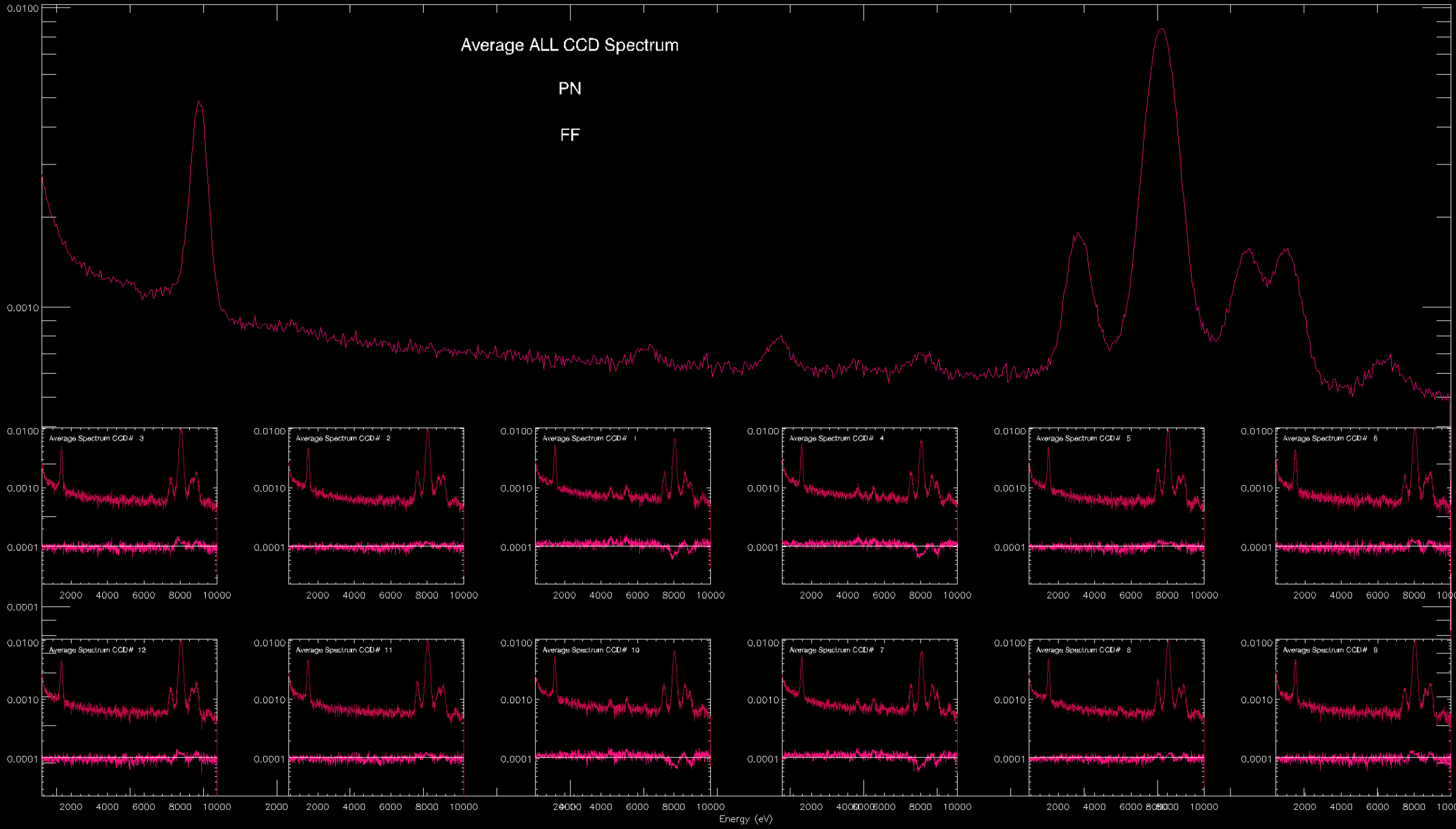
Derive HR (2.5-5.0 keV)/(0.4-0.8 keV)

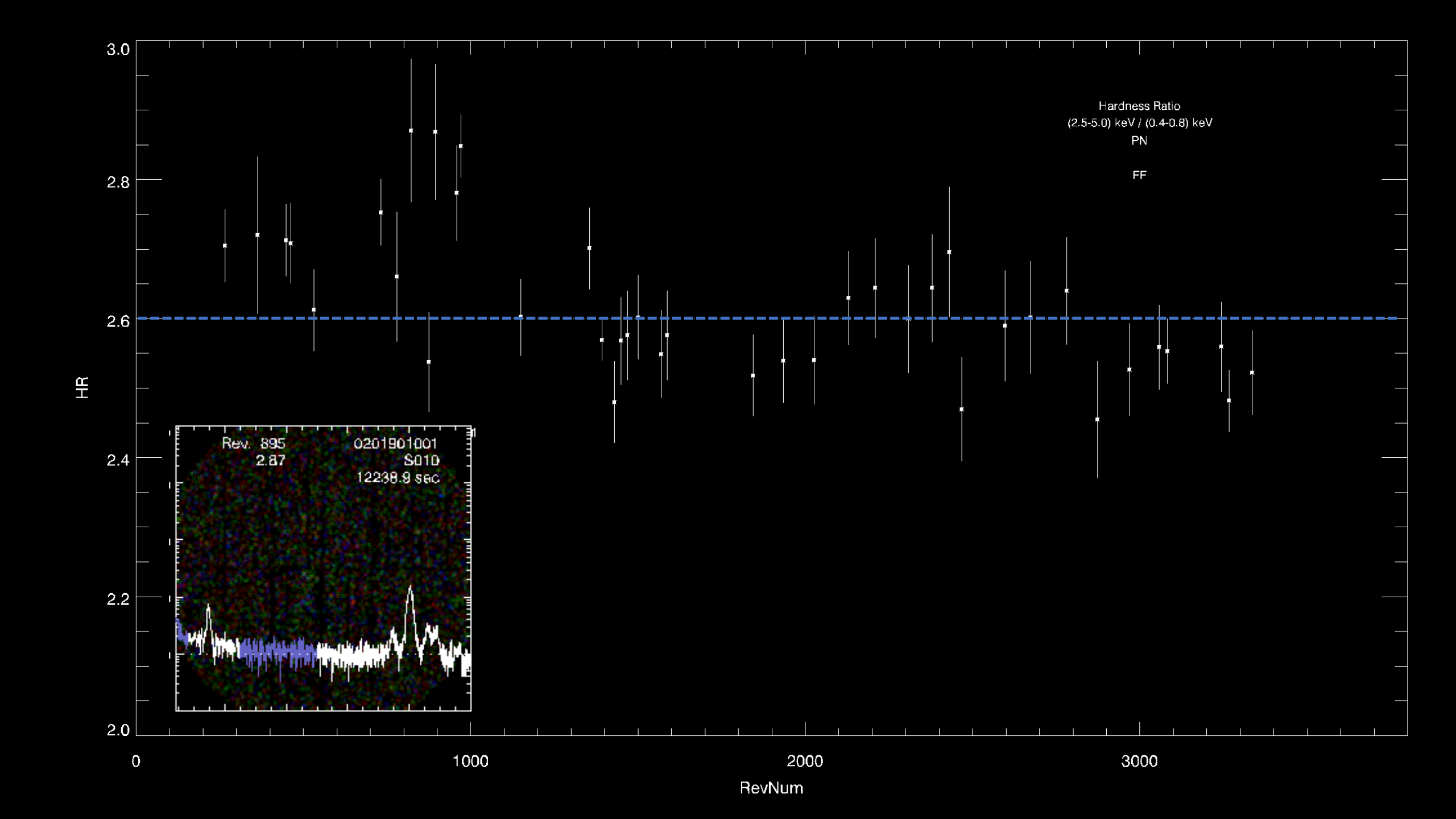

Mean FWC Spectrum
PN
FF
Normalized Counts
0.0100
0.0010
0.0001
(*) Mean +/- sqrt(Var)
Normalized to counts in 3.-7. keV
2000
4000
6000
8000
10000
Energy (eV)


RMS FWC Spectrum
Variance
8×10⁻⁶
6×10⁻⁶
4×10⁻⁶
2×10⁻⁶
2000
4000
6000
8000
10000
Energy (eV)


% Variation
%
100
80
60
40
20
0
20%
10%
0
2000
4000
6000
8000
10000
Energy (eV)


Average Spectra at 3 Time Epochs
PN
FF
< rev.1200
rev.1200- rev.2100
> rev.2100
0.0100
0.0010
0.0001
1.4
1.2
1.0
0.8
0.6
2000
4000
6000
8000
10000
Change of intensity with time (?)
(*) Ratio of epoch spectra / mean spectrum
8 keV


Average ALL CCD Spectrum
PN
FF
Average Spectrum CCD# 3
Average Spectrum CCD# 2
Average Spectrum CCD# 1
Average Spectrum CCD# 4
Average Spectrum CCD# 5
Average Spectrum CCD# 6
Average Spectrum CCD# 12
Average Spectrum CCD# 11
Average Spectrum CCD# 10
Average Spectrum CCD# 7
Average Spectrum CCD# 8
Average Spectrum CCD# 9
0.0100
0.0010
0.0001
2000
4000
6000
8000
10000
Energy (eV)


Hardness Ratio
(2.5-5.0) keV / (0.4-0.8) keV
PN
FF
HR
RevNum
3.0
2.8
2.6
2.4
2.2
2.0
0
1000
2000
3000
Rev. 895
2.87
0201901001
S010
12238.9 sec

Application to Science data to correct images and spectra

Use science data to define GTI periods from background LC

(100 sec bin, XMMEA_EP && (PI in [200:10000] && PATTERN==0))

Use science data to derive NDSLIN LC within GTI as defined from background LC,

Derive *Mean NDSLIN* $_{SCIENCE}$ within GTI

With Mean NDSLIN $_{SCIENCE}$ apply the following relation (derived from the FWC data):

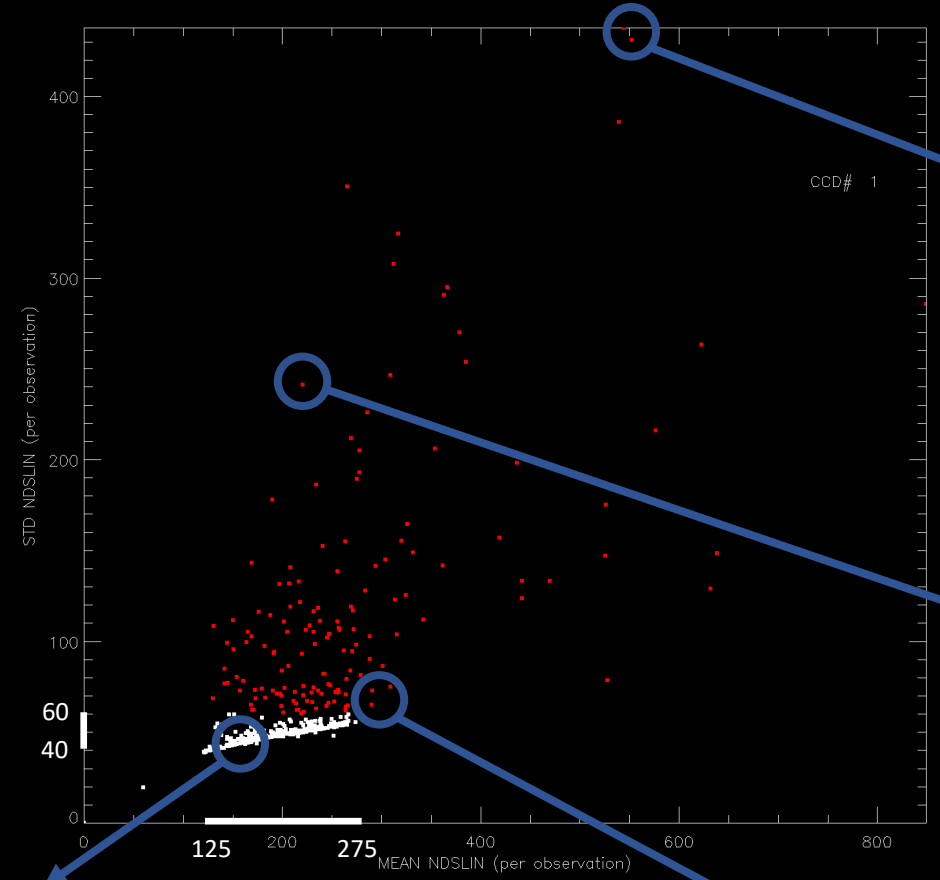
Mean BKG Rate $_{SCIENCE}$ (cts/sec) = 0.0154 * Mean NDSLIN $_{SCIENCE}$ + 0.3431 EPIC-pn FF

$$\text{Scale Factor}_{FWC} = \frac{\text{Mean BKG Rate}_{SCIENCE} * \text{Exposure Time}_{SCIENCE}}{\text{Mean BKG Rate}_{FWC} * \text{Exposure Time}_{FWC}}$$

Mean BKG Rate $_{FWC}$ = 2.950 ± 0.002 cts/sec

Exposure Time $_{FWC}$ = 5.97e+05 sec

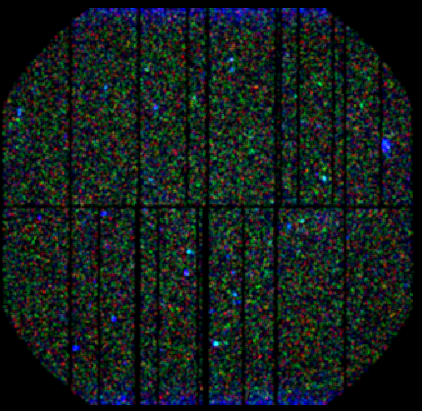
Mean vs STD NDSLIN

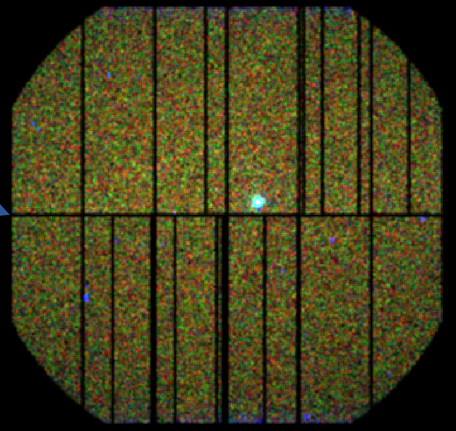


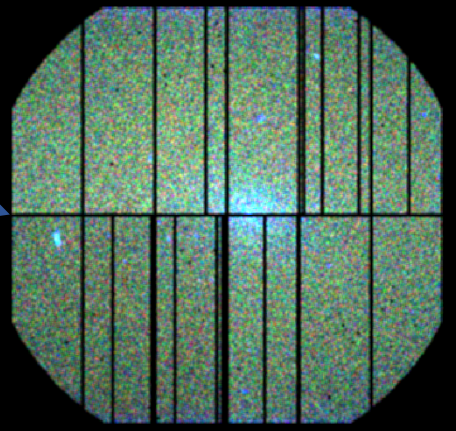
Image

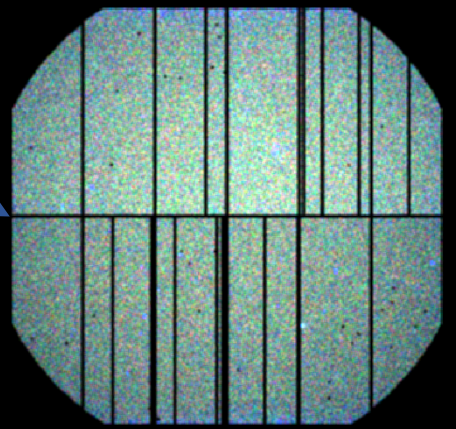
Red: 8.5-12 keV Green: 2-6 keV Blue: 0.2-2 keV

No BKG Filtered

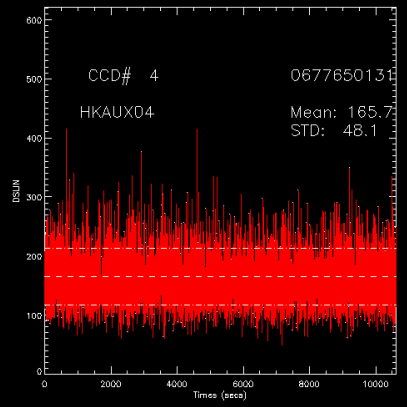


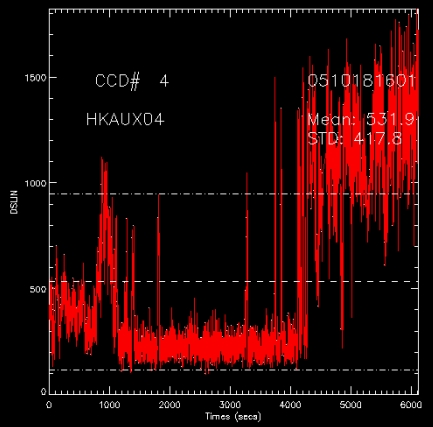


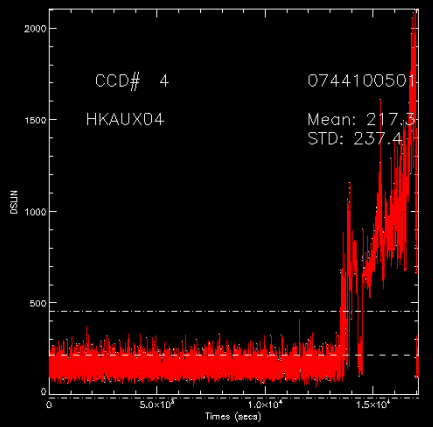


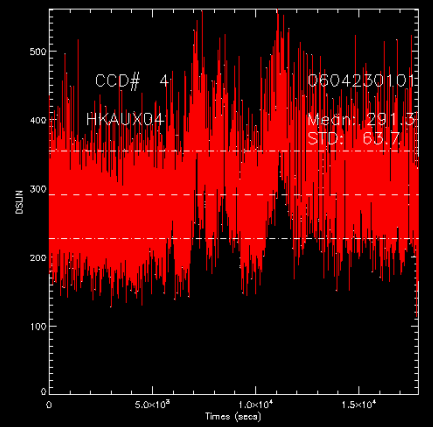


NDSLIN vs Time



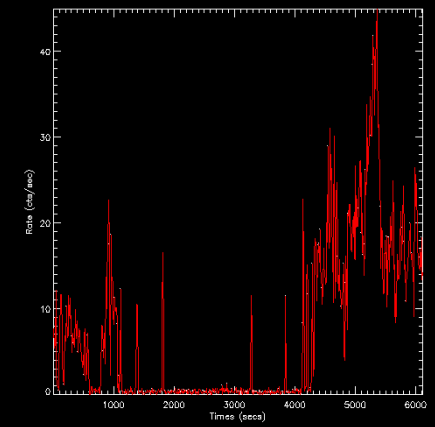


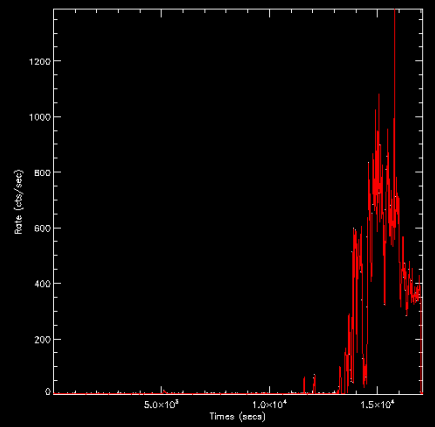


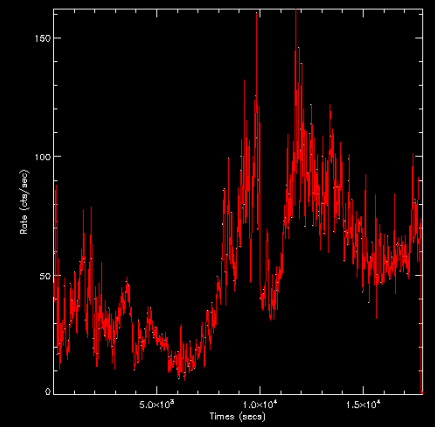


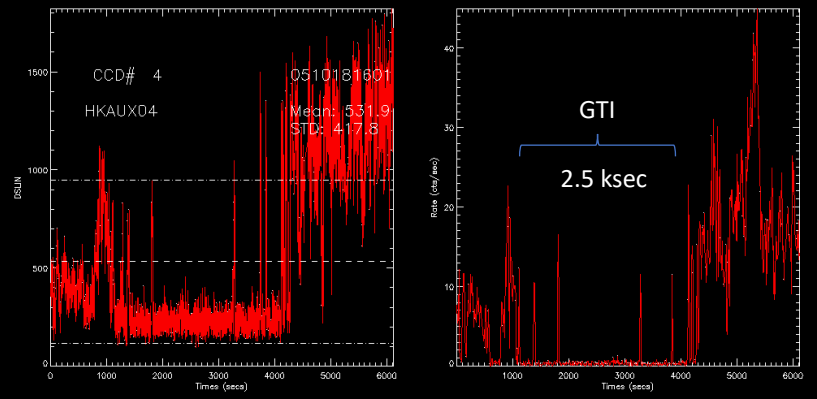
BKG Rate vs Time

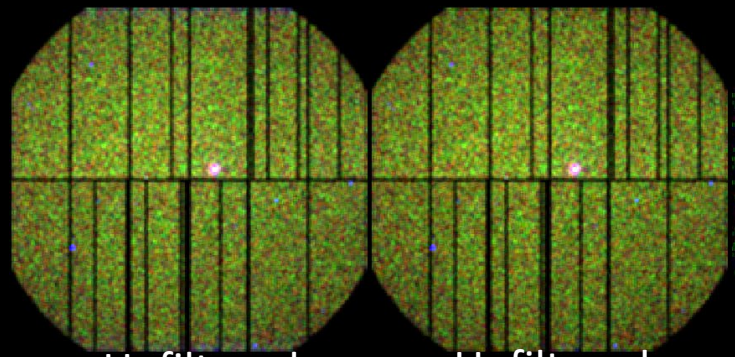
Full FOV, 0.5-7.5 keV





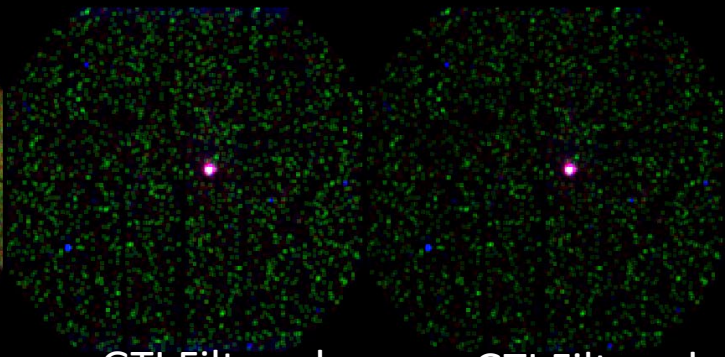






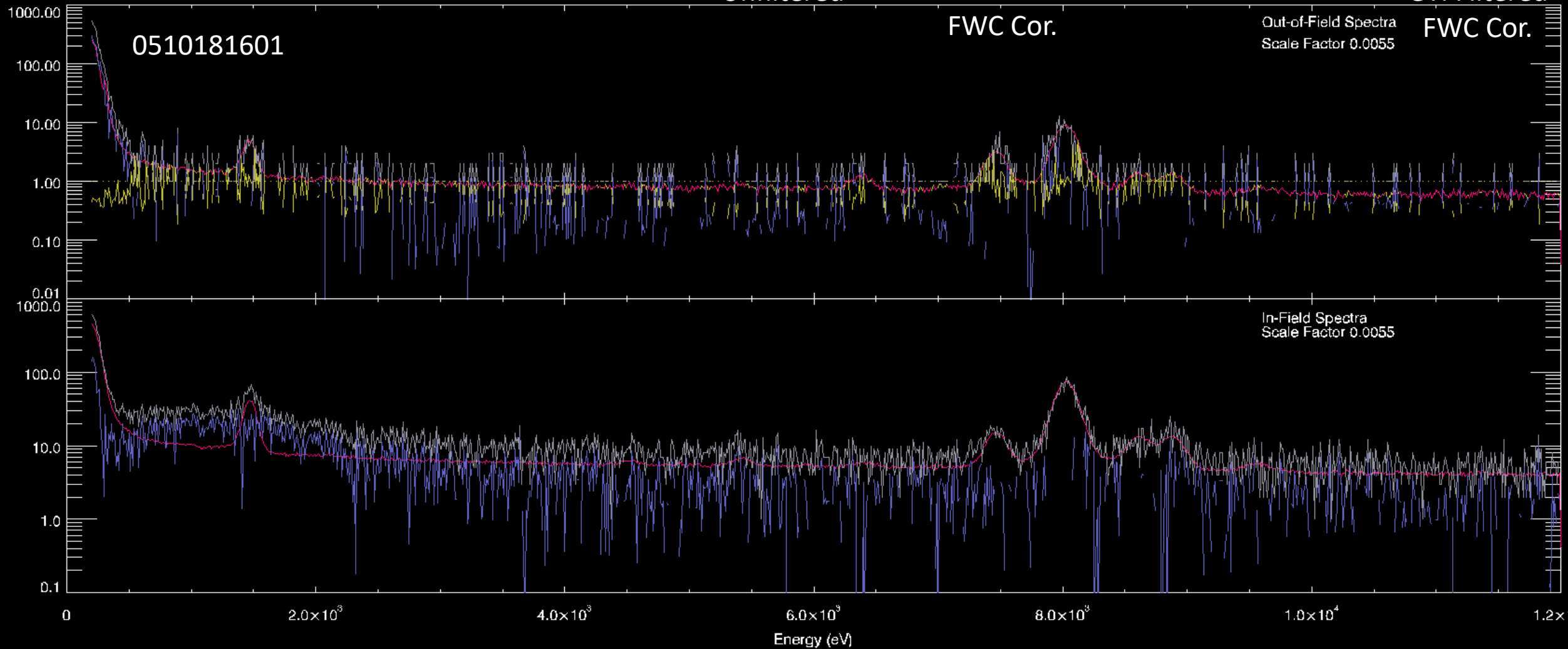
Unfiltered

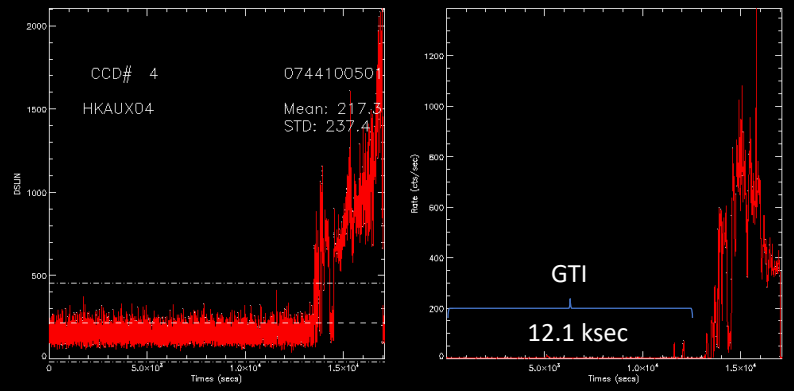
Unfiltered
FWC Cor.

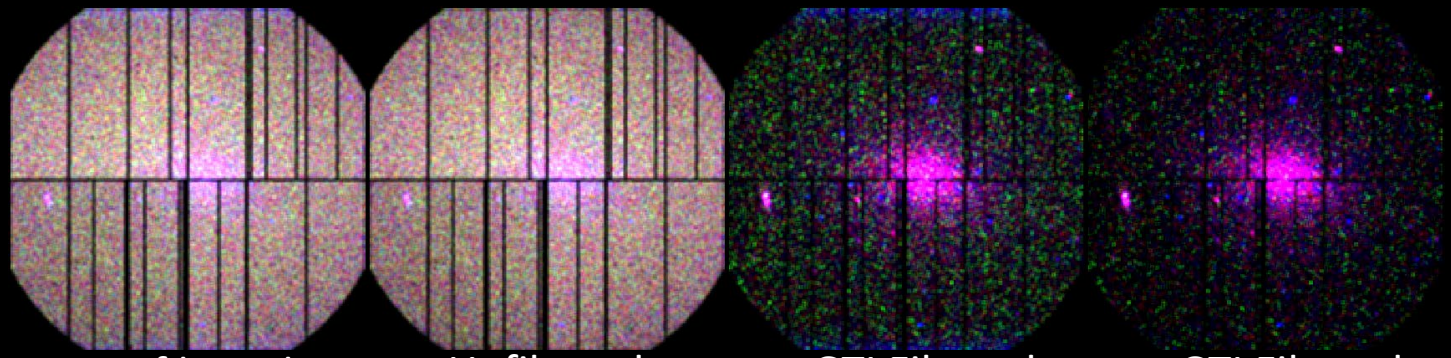


GTI Filtered

GTI Filtered
FWC Cor.







Unfiltered | Unfiltered | GTI Filtered | GTI Filtered

FWC Cor. | FWC Cor.

0744100501

Out-of-Field Spectra
Scale Factor 0.0181

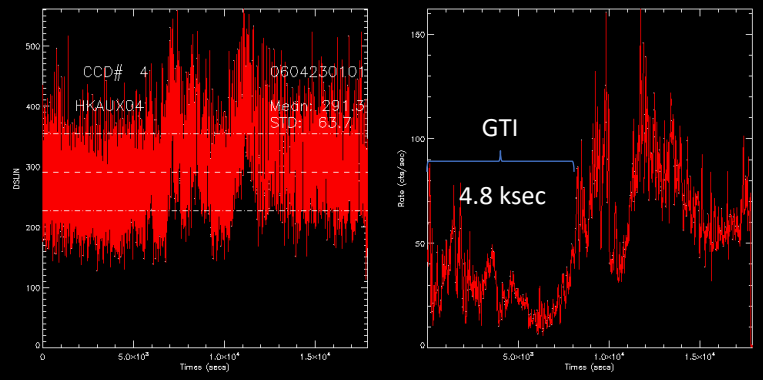
In-Field Spectra
Scale Factor 0.0181

1000.00
100.00
10.00
1.00
0.10
0.01

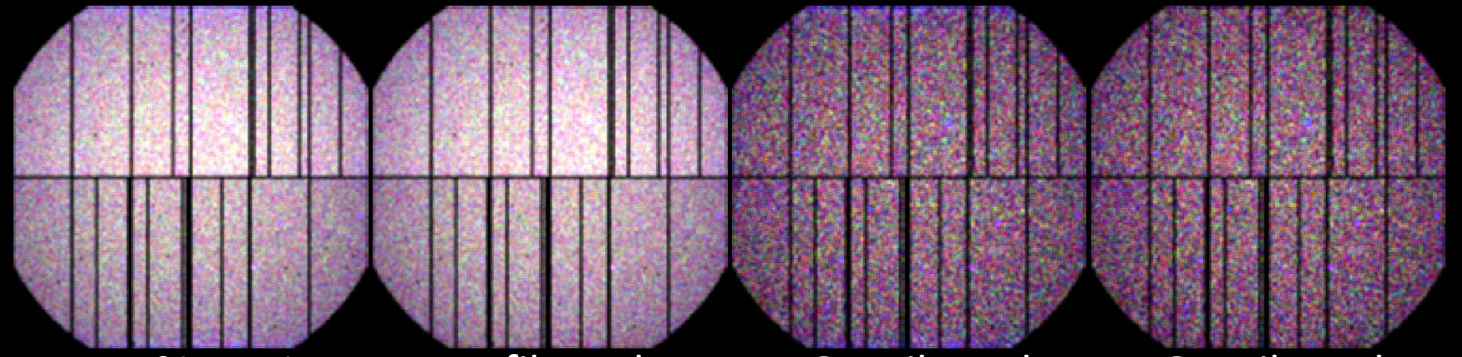
10000
1000
100
10
1

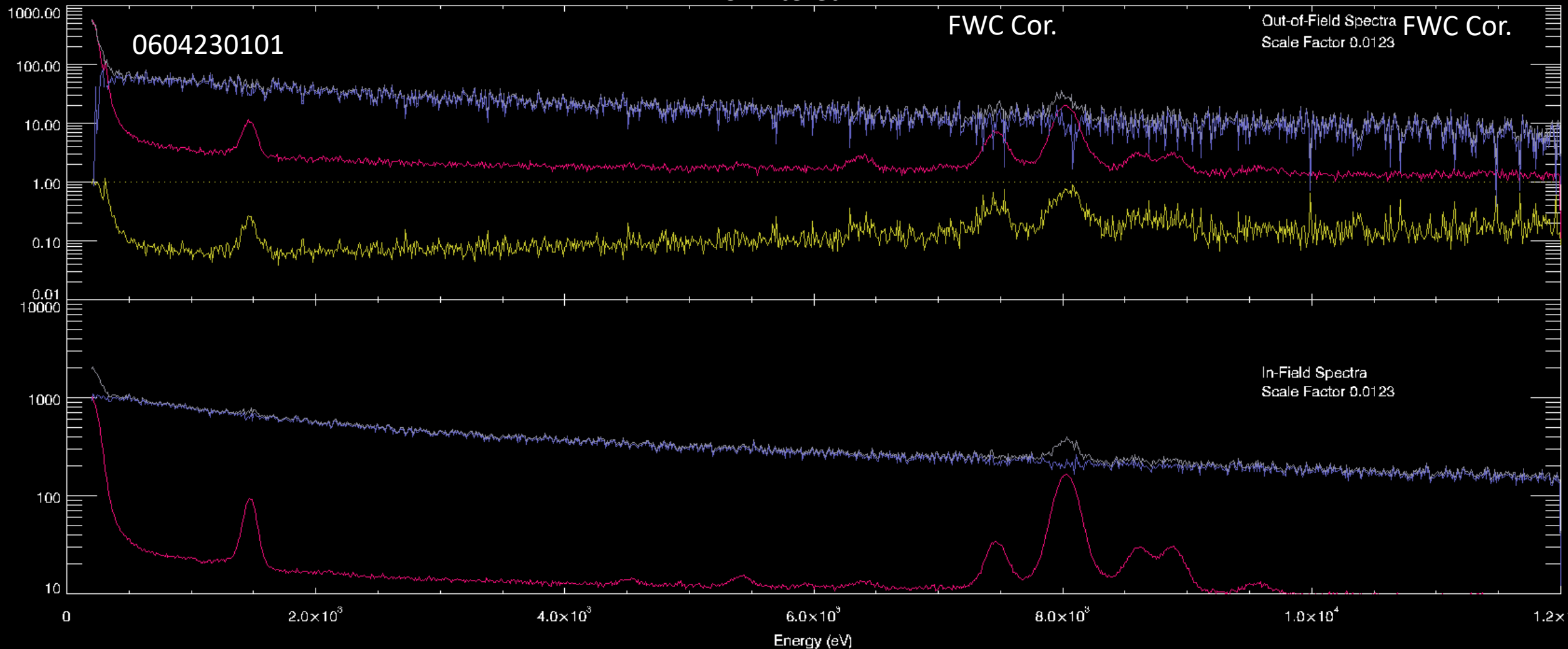
0
2.0×10³
4.0×10³
6.0×10³
8.0×10³
1.0×10⁴
1.2×10⁴

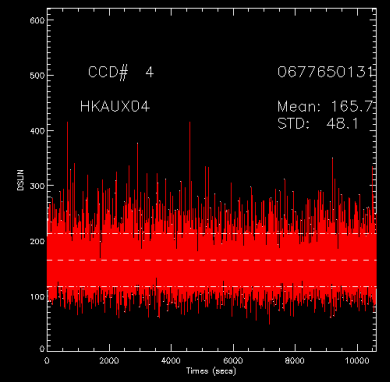
Energy (eV)

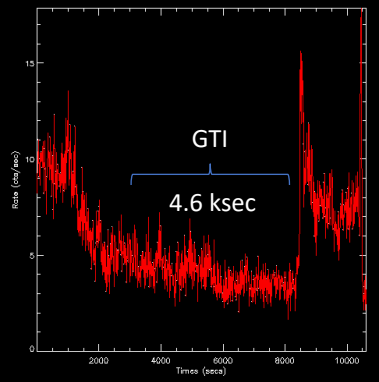

CCD# 4
HKAUX04
0604230101
Mean: 291.3
STD: 63.7
DSUN
Times (secs)

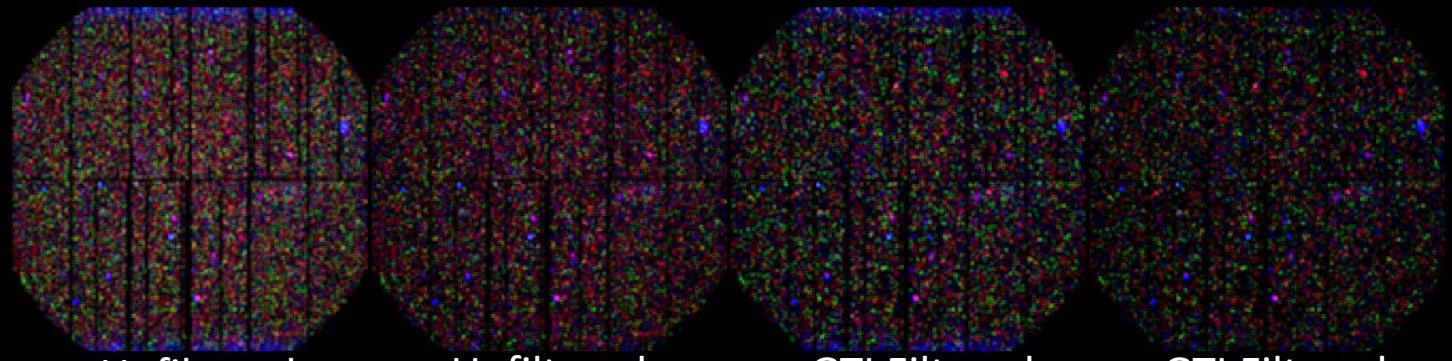
GTI
4.8 ksec
Rate (cts/sec)
Times (secs)


Unfiltered
Unfiltered
FWC Cor.
GTI Filtered
GTI Filtered

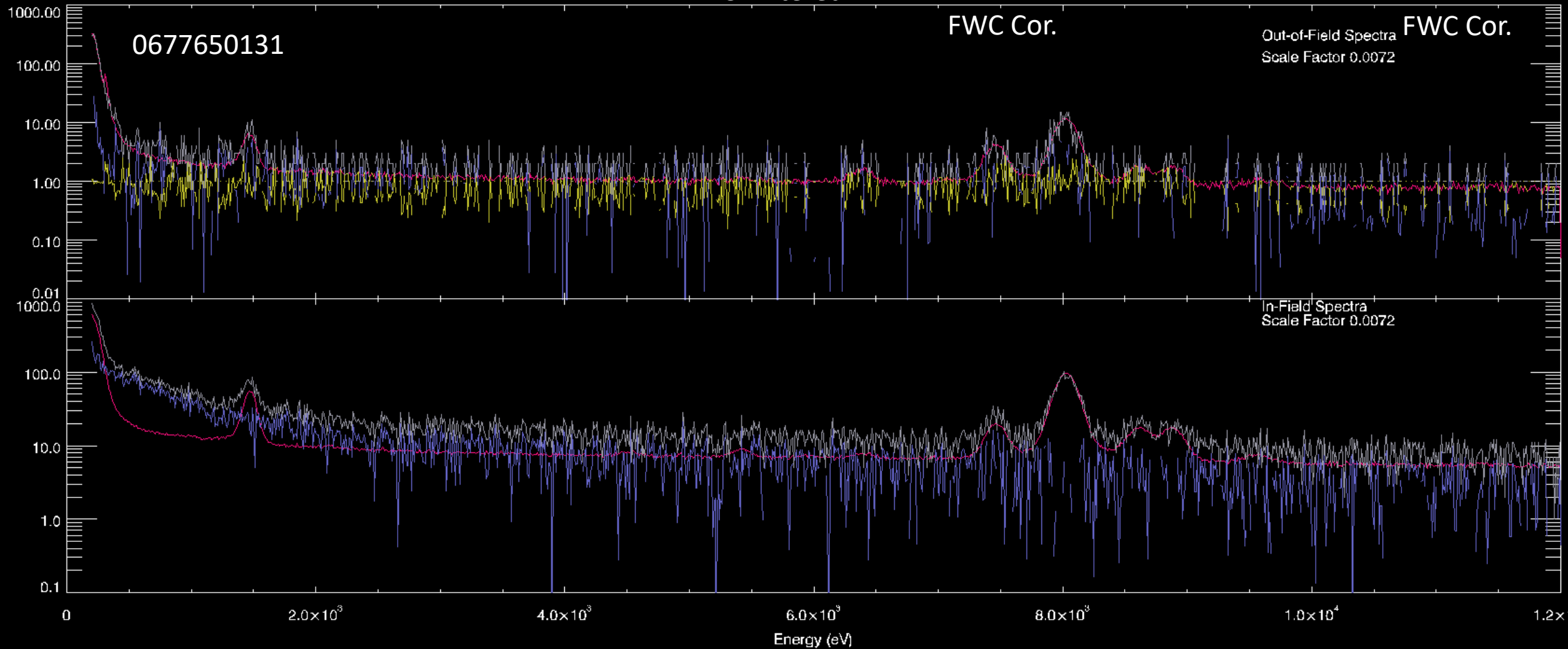

0604230101
Out-of-Field Spectra
Scale Factor 0.0123
FWC Cor.
In-Field Spectra
Scale Factor 0.0123
Energy (eV)







Unfiltered | Unfiltered FWC Cor. | GTI Filtered | GTI Filtered FWC Cor.

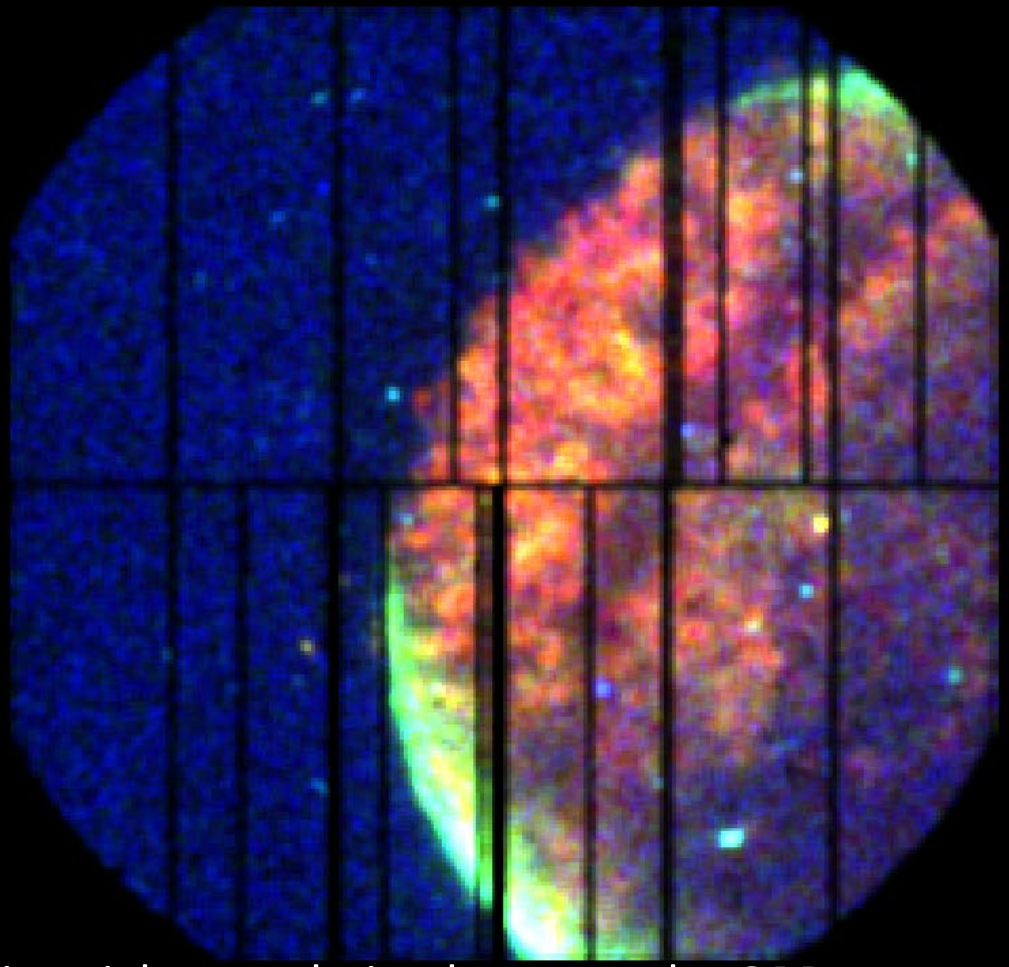


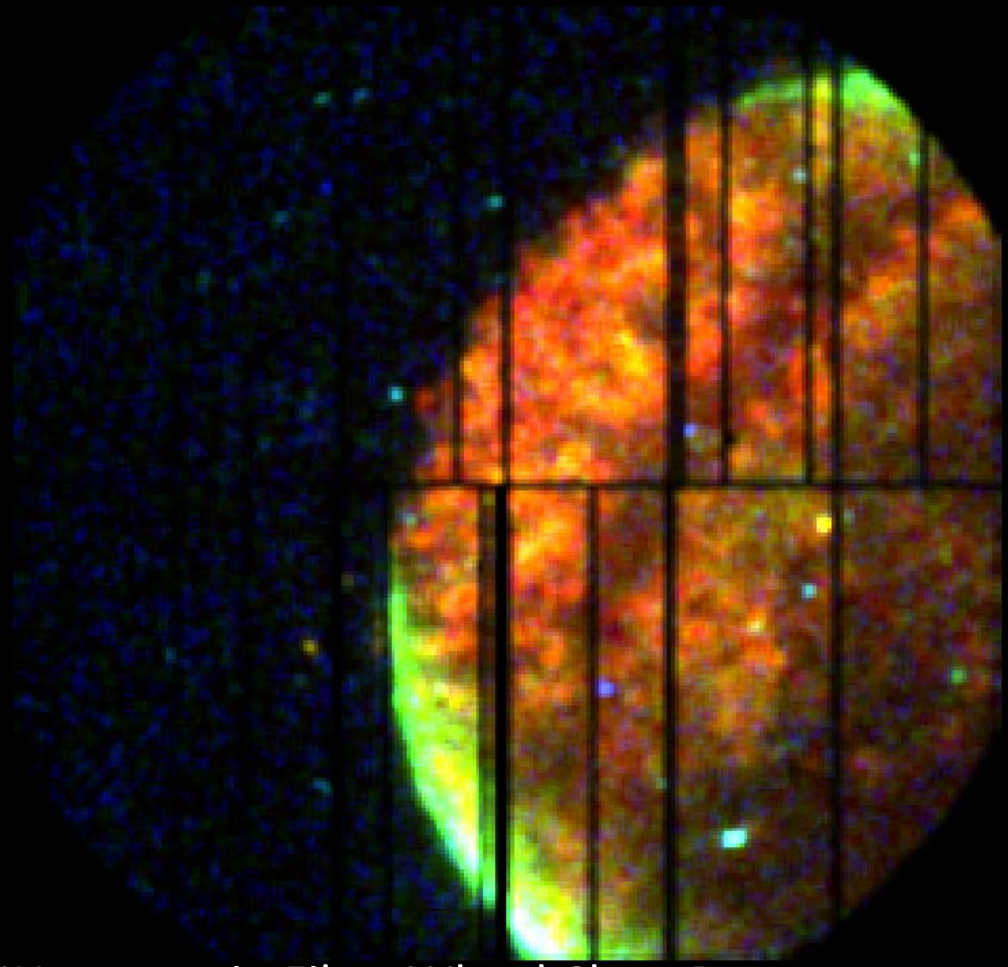
Conclusions

As of SASv17 NDSLIN is available on a time scale of 20 x frametime

SN1006-1
Rev.1594
0555630101

NDSLIN provides a good trace of the Quiescent Particle Background (QPB)

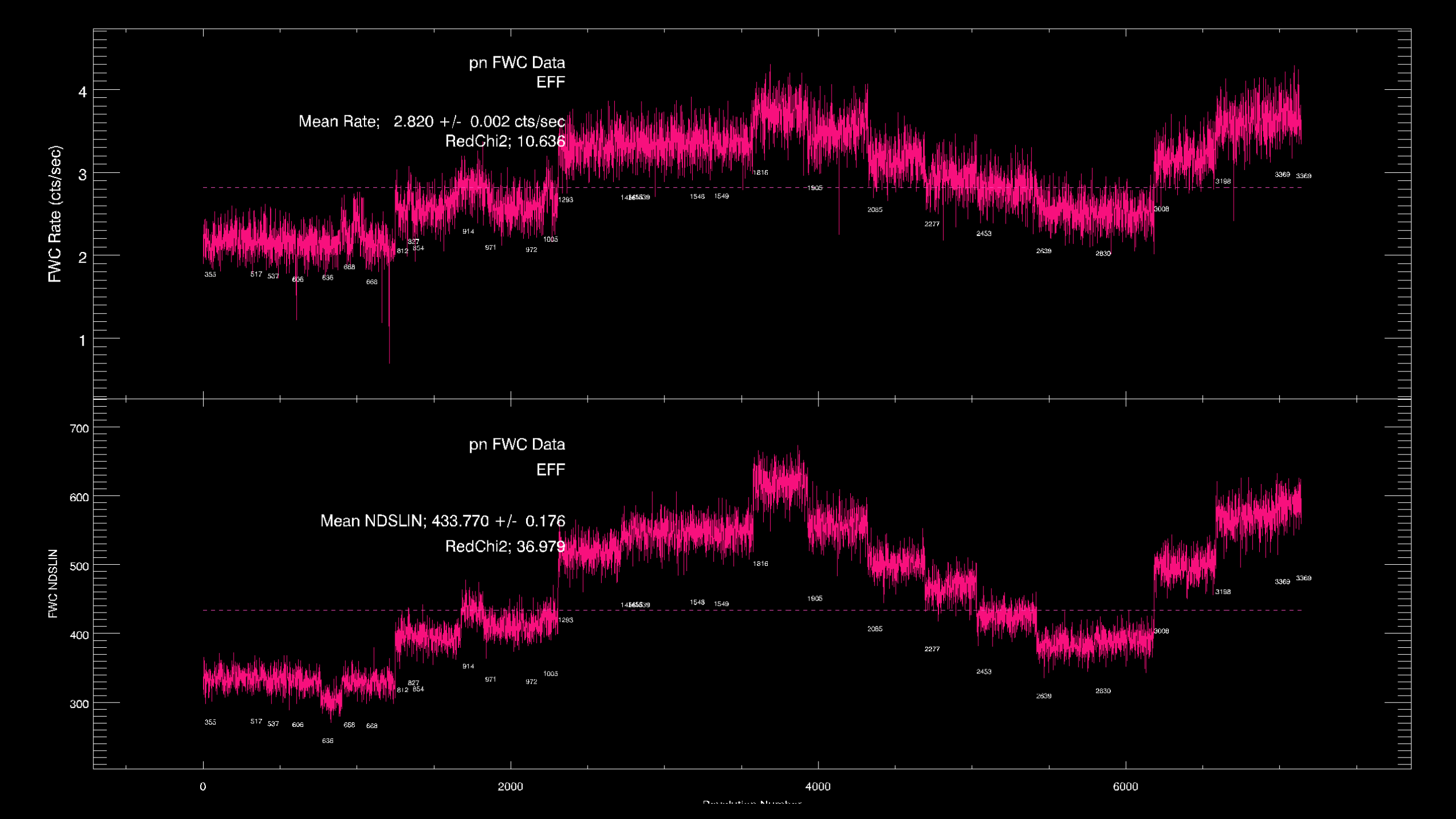


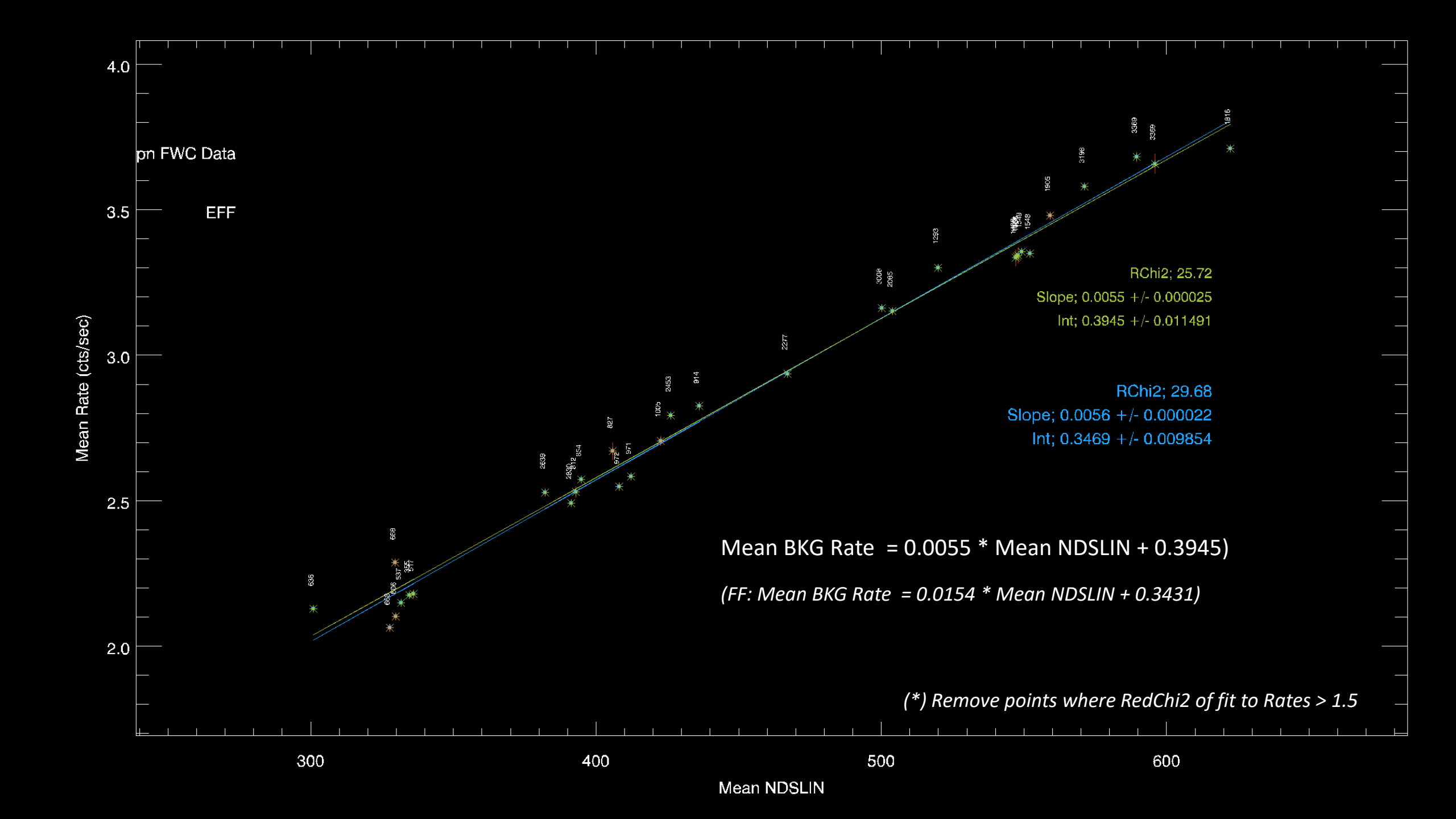


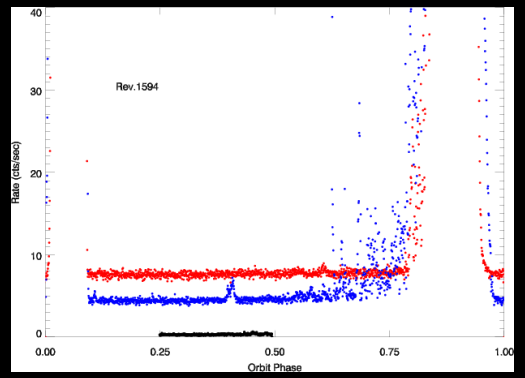
There is a tight correlation between the QPB rates and NDSLIN as seen in Filter Wheel Close Data

The mean value of the NDSLIN across a science observation **derived from periods of GTI** can be used to determine the level of QPB to be *removed* from the science observation: images and spectra

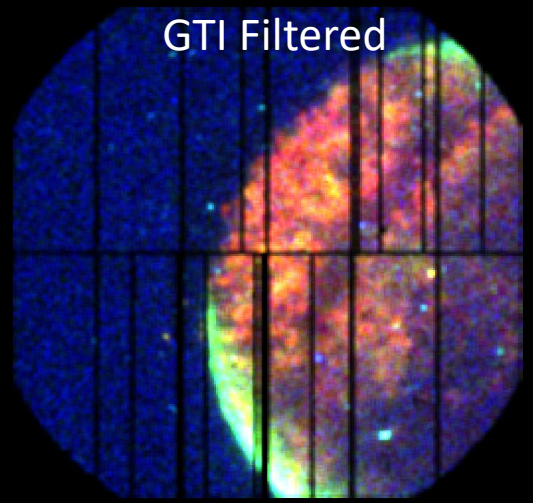
Extra Material


pn FWC Data
EFF
Mean Rate; 2.820 +/- 0.002 cts/sec
RedChi2; 10.636
FWC Rate (cts/sec)
pn FWC Data
EFF
Mean NDSLIN; 433.770 +/- 0.176
RedChi2; 36.979
FWC NDSLIN
0
2000
4000
6000

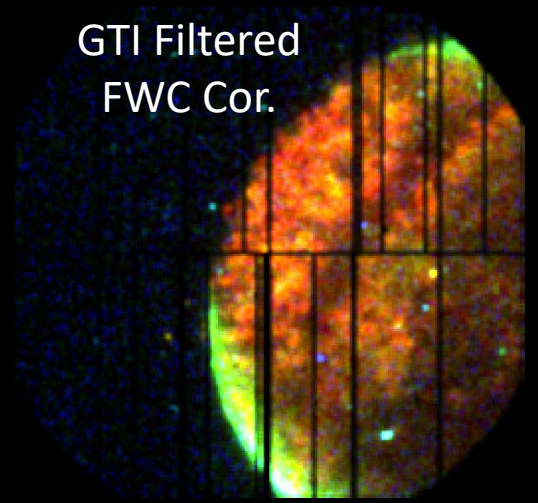

pn FWC Data
EFF
Mean Rate (cts/sec)
Mean NDSLIN
4.0
3.5
3.0
2.5
2.0
300
400
500
600
RChi2; 25.72
Slope; 0.0055 +/- 0.000025
Int; 0.3945 +/- 0.011491
RChi2; 29.68
Slope; 0.0056 +/- 0.000022
Int; 0.3469 +/- 0.009854
Mean BKG Rate = 0.0055 * Mean NDSLIN + 0.3945)
(FF: Mean BKG Rate = 0.0154 * Mean NDSLIN + 0.3431)
(*) Remove points where RedChi2 of fit to Rates > 1.5



GTI Filtered



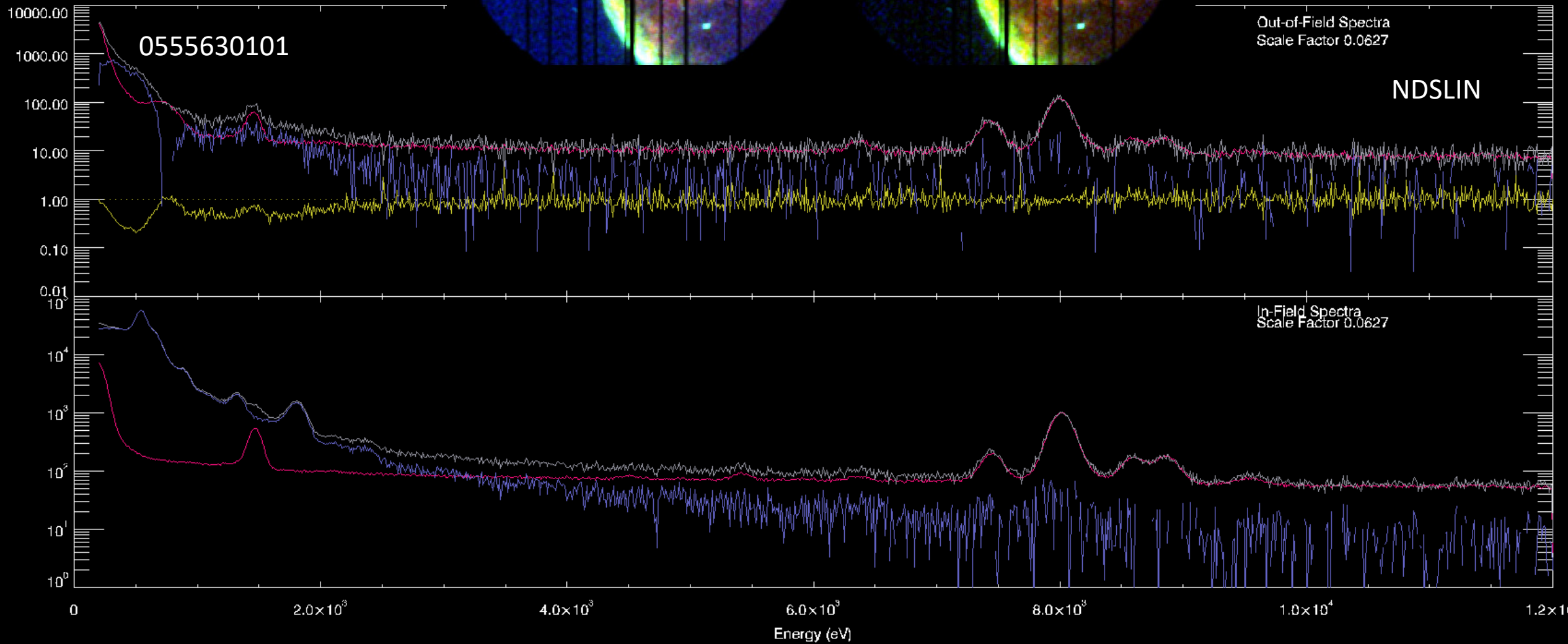
GTI Filtered
FWC Cor.

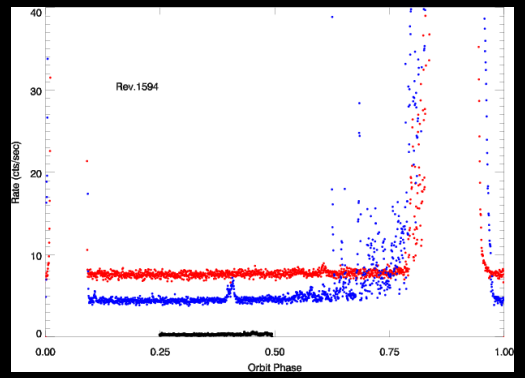


SAS evqpb

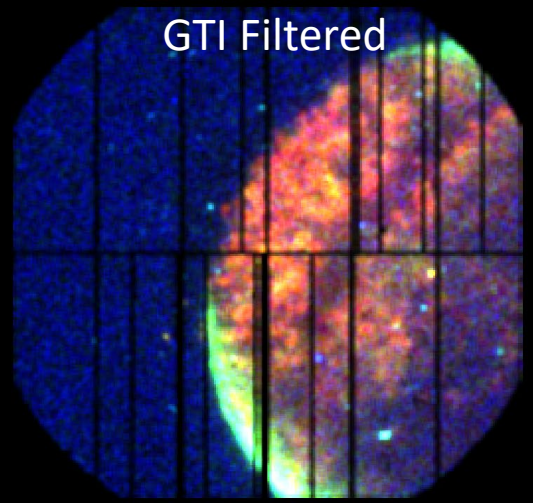
vs NDSLIN

0555630101





GTI Filtered



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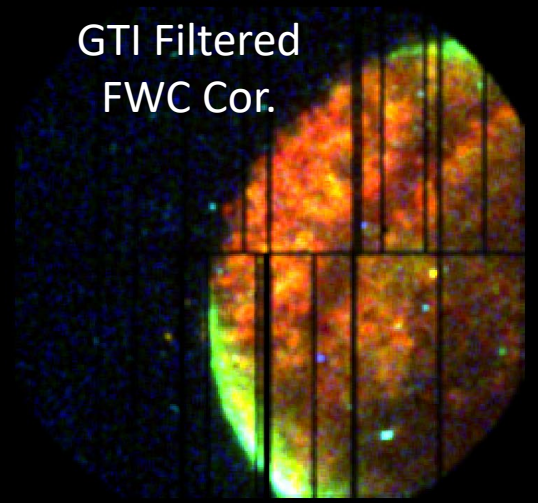

SAS evqpb

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