Analytic modelling of the PN particle background spectrum

Chen Wang (Speaker)   Jean Ballet

AIM, CEA-Saclay, France

2022.04.27

Outline

- **Introduction**
- **Previous work**

  Decomposition into patterns

  Analytic models for spectrum of each pattern (single, horizontal-pixel events and vertical-pixel events)

  The emission lines, *Lorentz* model instead of *Gaussian* model.
- **Global model for (pattern=0) and (pattern [0:4]). (Not divided into patterns.)**

  Adapt to different locations of the detector.

  CCD

  RawY

  Random regions
- **Model for Users (Pattern=0 and Pattern [0:4])**

  Free and fixed parameters

  Lines
- **Comparison with Richard Sturm's model**

  Accuracy

  Stability

Background handling in spectral fitting

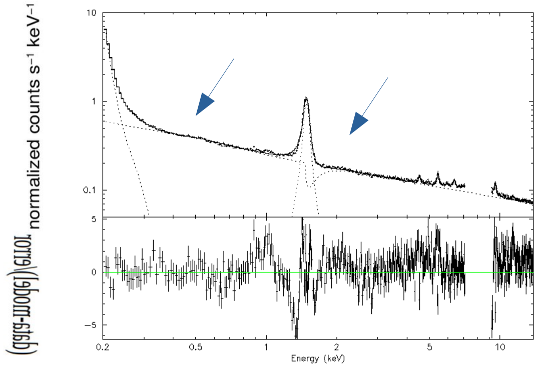
- Most critical for extended sources
- Science: extract spectra in source, background regions and FWC in the source region, fit together
- Best to **fit common model with linked parameters** (naturally accounts for statistical fluctuations in the background spectrum)
- Background is astrophysical + lines + **particle background**

The RMF file we used for the continuum part of the spectrum is diagonal matrix.

- PN particle background more difficult (no large out-of-FOV area)
- Objective: find **analytic model** from Filter-Wheel Closed spectra
- Starting point is M. Freyberg’s work

Previous work about pattern=0 spectra

Richard Sturm:



Model for single-pixel events:

1, spline*exp + powerlaw

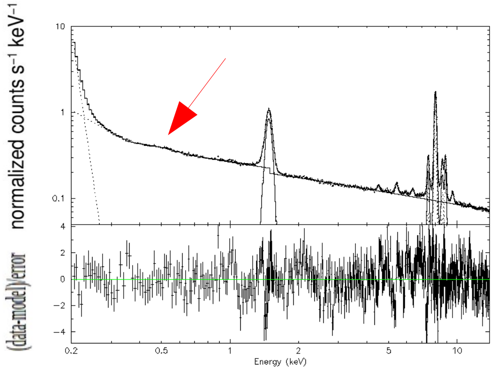
2, Two smedge:

$$M(E) = \begin{cases} 1 & E < E_c \\ \exp\left[-f(E/E_c)^{\alpha}\right]\left[1 - \exp((E_c - E)/W)\right] & E \geq E_c \end{cases}$$

3, Gaussian lines

Only the diago RMF for the continuum part and the lines.

Our model :



For the continuum part (diago RMF)

Powerlaw for the soft energy band (start at 0.2 keV)

Broken powerlaw

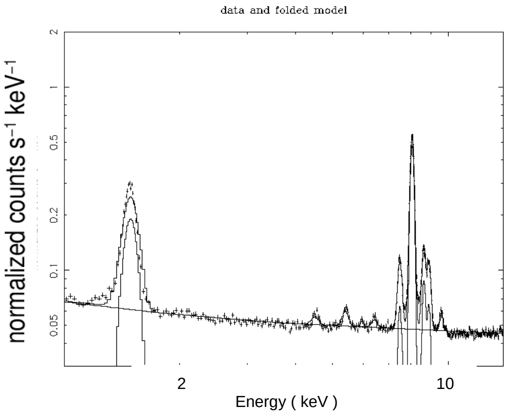
Small features

Smedge ~ 0.5 keV
Step ~ 1.5 keV

For the emission lines

Lorentz with the instrumental RMF

The emission lines



- Correlation with the continuum part.
- The small lines between 4 – 7 keV are in scientific important band and too faint to be fitted individually by the user.

About the model:

- Central energies are linked together based on the theoretical value
- Normalization ratios are fixed within the same elements
- ***Lorentz*** model improves the fit !

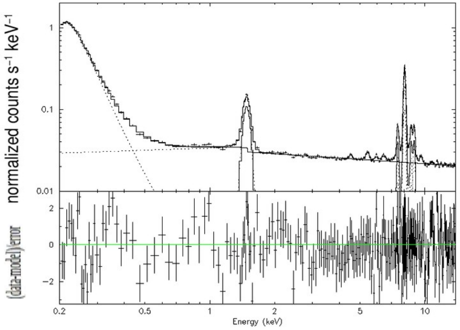
Element	$K_{\alpha1}$	$K_{\alpha2}$	$K_{\beta1}$	$L_{\alpha1}$ / $L_{\alpha2}$
In the unit of eV				
Cu (referrence)	8,047.78	8,027.83	8,905.29	
Al	1,486.70	1,486.27		
Ti	4,510.84	4,504.86		
Cr	5,414.72	5,405.509	5,946.71	
Fe	6,403.84	6,390.84	7,057.98	
Ni	7,478.15	7,460.89	8,264.66	
Zn	8,638.86	8,615.78	9,572.0	
Au				9,713.3/9,628.0

Table : Fluorescence lines included in the FWC spectral model.

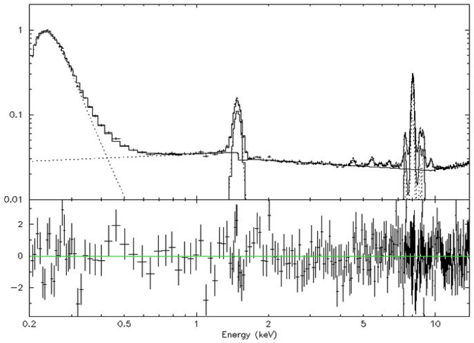
How to deal with the width :
For the lines of the same element, the widths were linked.
Eventually, most widths were fixed (Based on the fit results over the full data).

The analytic models for each pattern of double pixel events

Pattern=1



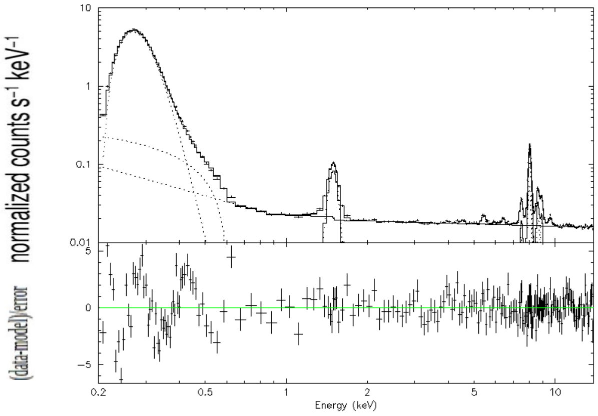
Pattern=3



A κ-velocity distribution.

A broken power law (pattern=1) **or** a ***double*** broken power law model (pattern=3).

Lorentz for each fluorescence line.



For horizontal-pixel events

A κ-velocity distribution

A broken power-law model.

A linear model *(Maximum(1-A*E, 0))* .

Lorentz for each fluorescence line.

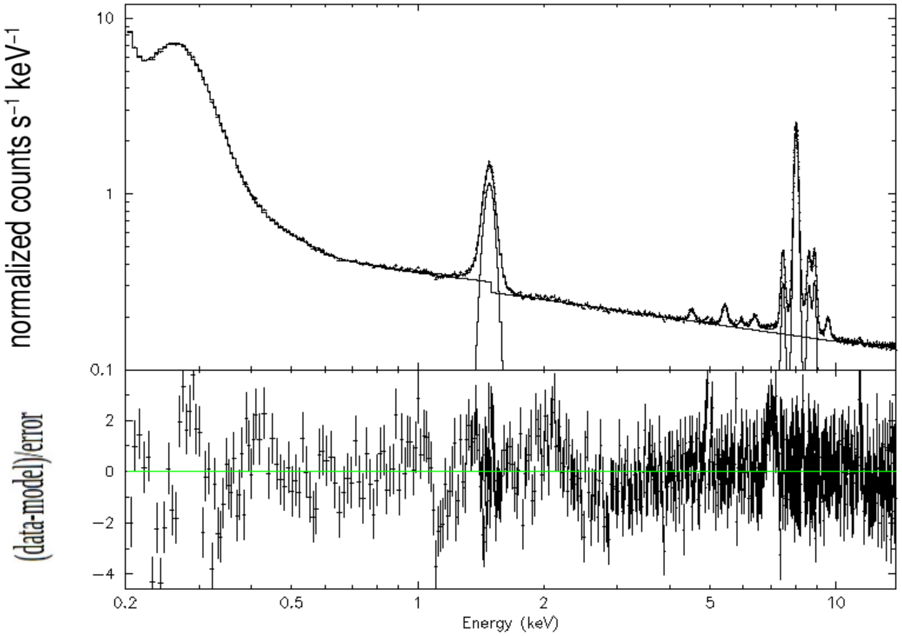
κ-velocity distribution:

$$C\frac{E'^2}{(1+E'^2/(\kappa-3/2))^{\kappa+1}}$$

$$E' = (E - E_0)/\Delta E$$

Nicholls et al. (2012, ApJ 752, 148)

Summed up model for Spectra of Pattern<=4



- Summed up models with the frozen parameters.
- Lorentz for each line.

The residuals are within 5 sigma.

The problem with the added-up model

Normally the user's selection is either (pattern=0) or (pattern<=4)

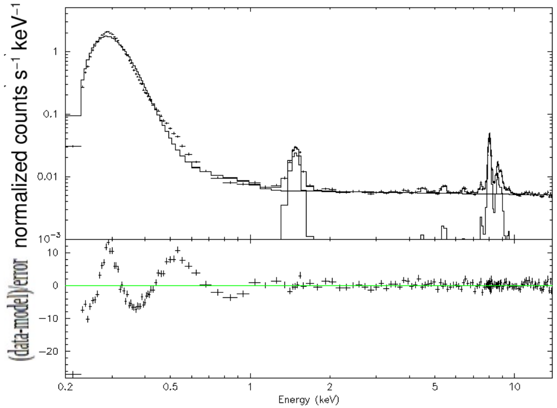
- **The original idea was to fit only the normalization of each component.**

However, when testing the model with different selections

The model with fixed shape parameters is not flexible enough regarding the ***spectral variation*** with position (CCD dependence, RAWY dependence ……) .

Leaving all the shape parameters free would not be stable on the summed-up spectra.

Additionally, some difference between the patterns vanish (especially > 0.5 keV) or become less significant after adding up the patterns. It is not necessary to divide the spectra into patterns.



RAWY > 150, horizontal pixel events (pattern=2 || pattern=4)

Therefore, a global model with free shape parameters

A global model for summed up spectra (pattern in [0:4])

	Fixed parameters		Free parameters
• Power law (start at 0.2 keV)	Gamma	;	Norm
• A κ-velocity distribution.	κ	;	E0 , delta-E, Norm
• A broken power law model.	The second Gamma, break energy	;	First-Gamma, Norm
• Notch model	LineE, width	;	Norm

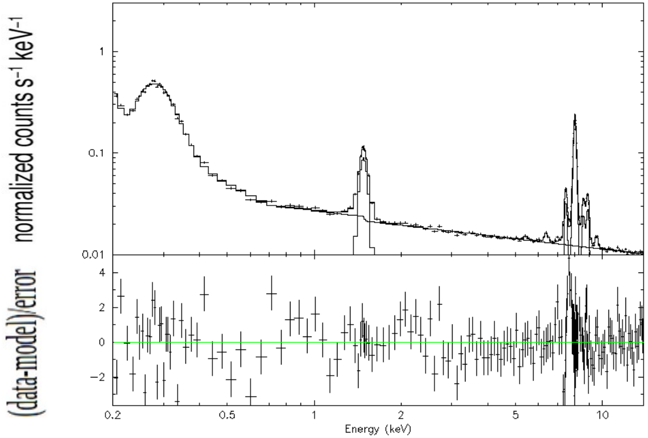
$$C \frac{E'^2}{(1 + E'^2/(\kappa - 3/2))^{\kappa+1}}$$

$$E' = (E - E_0)/\Delta E$$

7 free parameters

And, Lorentz for each fluorescence line.

CCD 5 (Pattern<=4)



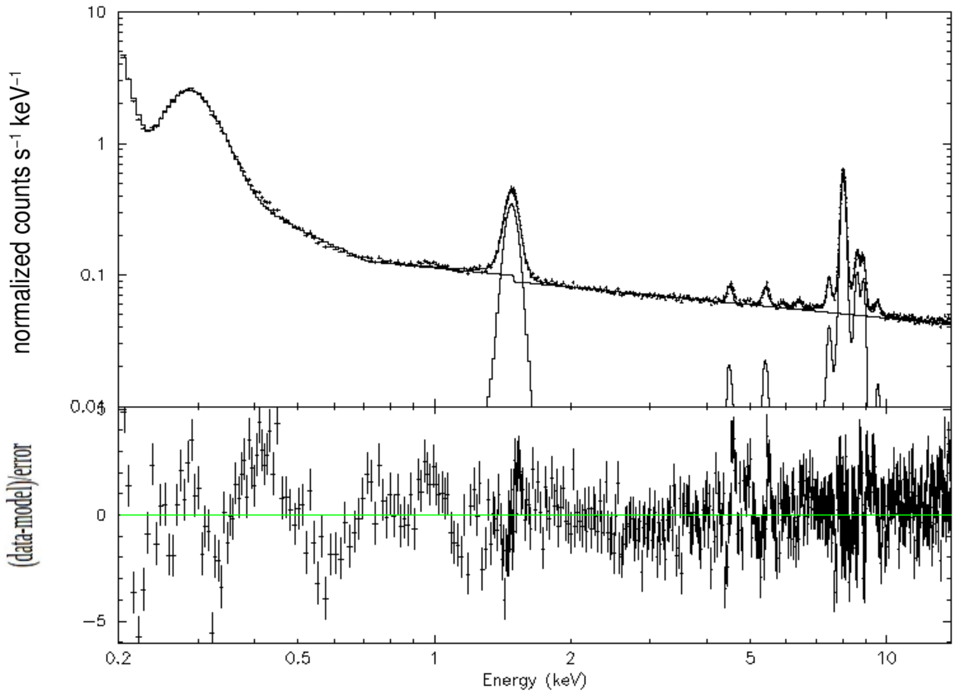
The problem with the new model

Problem with the kappa law model **:**

RawY dependence

Soft energy band, 0.2-0.5 keV.
(even with totally free kappa velocity model).

RawY > 150
Pattern<=4



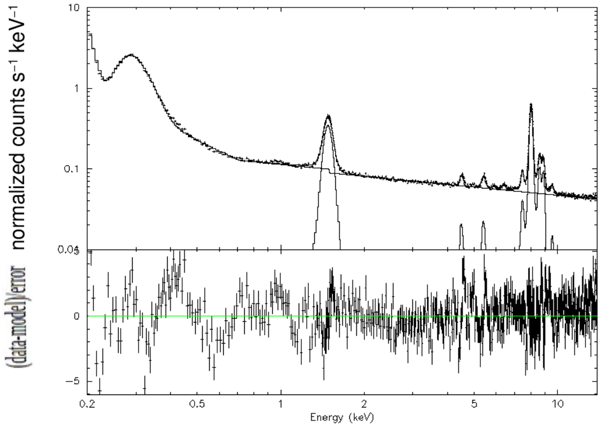
The modified Kappa-law model for summed up spectra

Modified κappa-law model : $$M \times C \frac{E'^2}{(1 + E'^2/(\kappa - 3/2))^{\kappa+1}}$$

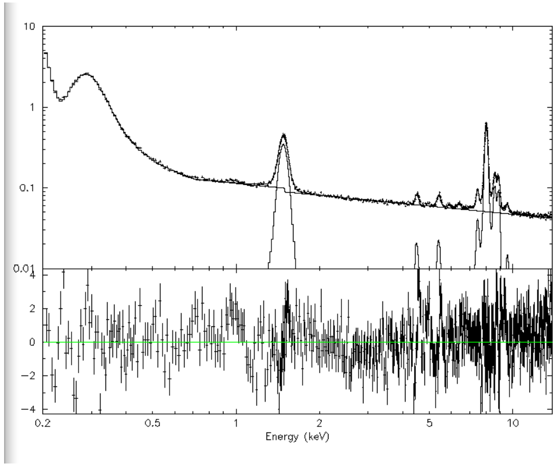
$$E' = (E - E_0)/\Delta E$$

$$M = \left[1 + \left(\frac{E'}{B}\right)^{10}\right]^{0.4}$$

κappa-law model



Modified κappa-law model



RawY > 150
Pattern <=4

The model for summed up (pattern<=4) spectra

	Fixed parameters		Free parameters
• Power law (start at 0.2 keV)	*Gamma*	;	Norm
• A modified κ-velocity distribution.	*κ, B*	;	E_0, delta-E, Norm
• A broken power law model.	*Break energy, Second-Gamma*	;	First-Gamma, Norm
• Notch model	LineE, *width*	;	Norm

$$M \times C \frac{E'^2}{(1+E'^2/(\kappa-3/2))^{\kappa+1}}$$

$$M = \left[1 + \left(\frac{E'}{B}\right)^{10}\right]^{0.4}$$

$$E' = (E - E_0)/\Delta E$$

7 free parameters

Lorentz for each fluorescence line.

Global shift : *Energy of each line linked to reference line Cu (~ 8.0 keV)*

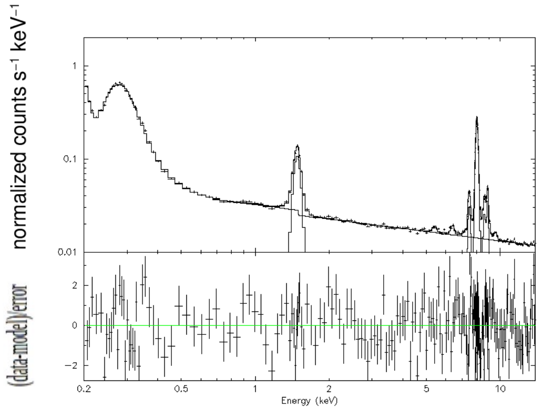
Same element: *Link the norm of the lines of the same elements.*

Free parameters:

Energy of the reference line
Width of reference line Cu (~ 8.0 keV) and Al line (~1.5 keV)
Each element with only one free norm

11 free parameters

CCD 3
Pattern <= 4



Model for pattern=0 spectra

	Fixed parameters	Free parameters
Power law (start at 0.2 keV)	Gamma	Norm
A broken power law model.	Break energy, Second-Gamma	First-Gamma, Norm
Notch model	LineE, width	Norm
Smedge	**All**	**None**

4 free parameters

Lorentz for each fluorescence line.

Global shift : *Energy of each line linked to reference line Cu ~ 8.0 keV*

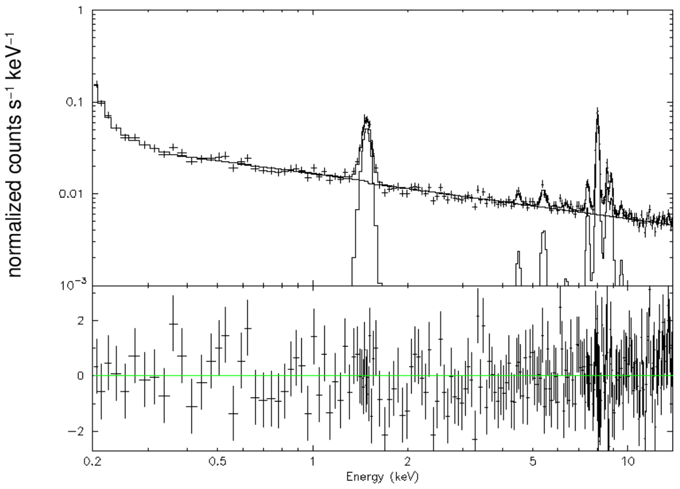
Same element: *Link the width and norm of the lines of the same elements.*

Free parameters:

Energy of the reference line
Width of reference line Cu (~ 8.0 keV) and Al line (~1.5 keV)
Each element with only one free norm

11 free parameters

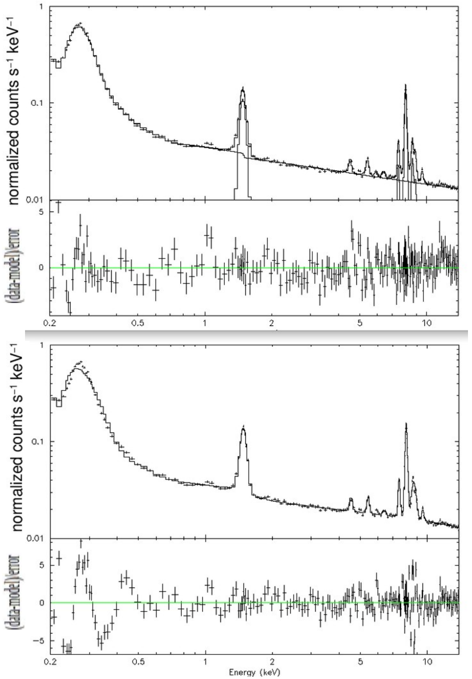
A circle with about 100 ks exposure; pattern=0



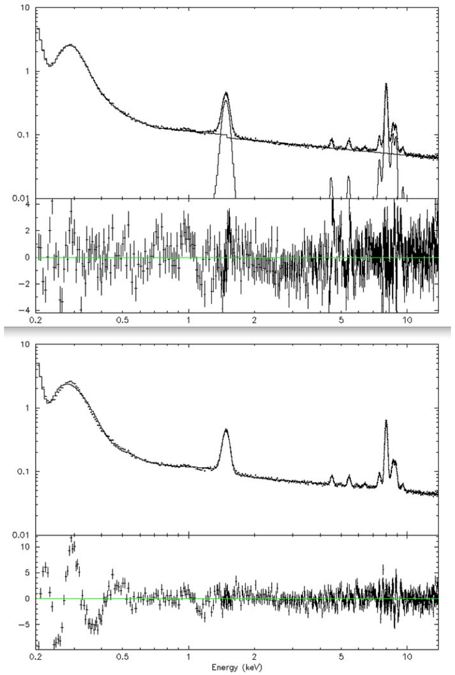
Comparison with Richard Sturm's model (Pattern<=4)

- **The stability** **(Fewer free parameters, more stable).**
- **The accuracy** **(The soft energy band is better fitted).**

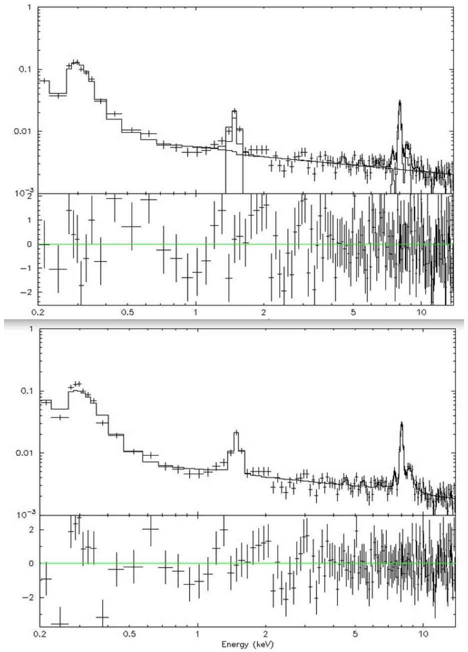
CCD : (ccd4)



RawY : (>150)



Random circle with exposure time ~100 :



New :

Richard Sturm

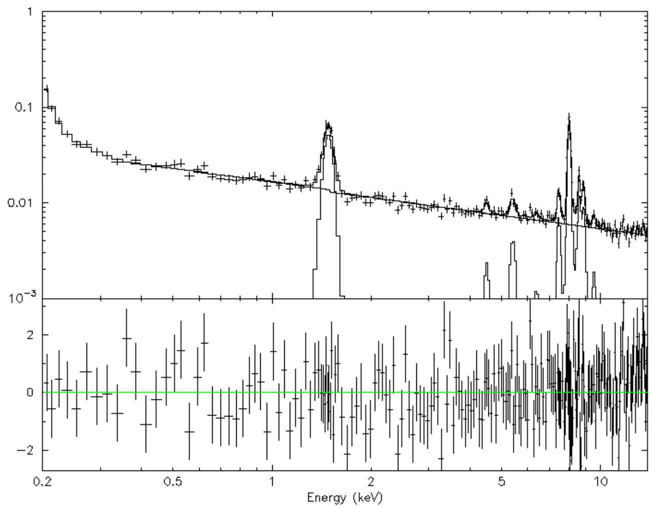
Comparison with Richard Sturm's model (Pattern=0)

Comparable fitting results

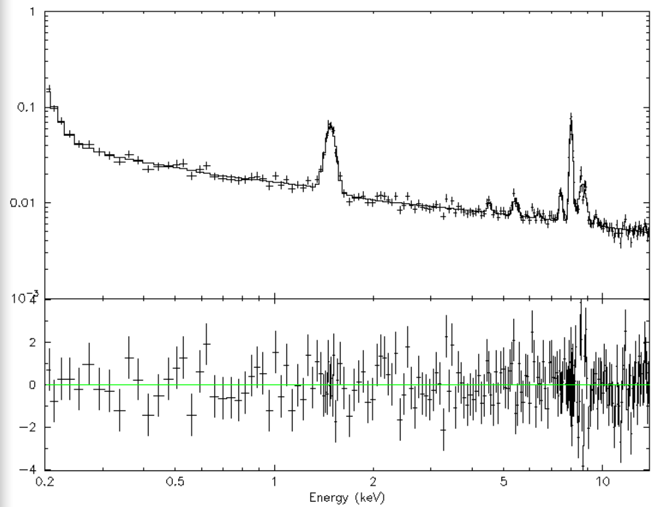
Fewer free parameters

Circle region
Exposure ~ 100 ks
pattern=0

New



Richard Sturm's



Conclusion

- Global models for summed up (pattern <=4) spectra and single pixel events spectra (pattern=0) which can adapt to different locations in the detector.
- The accuracy and stability is generally better than the currently used (Richard Sturm’s) model
- Lorentz model for lines works better than Gaussian.