# Analytic modelling of the PN particle background spectrum

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# 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

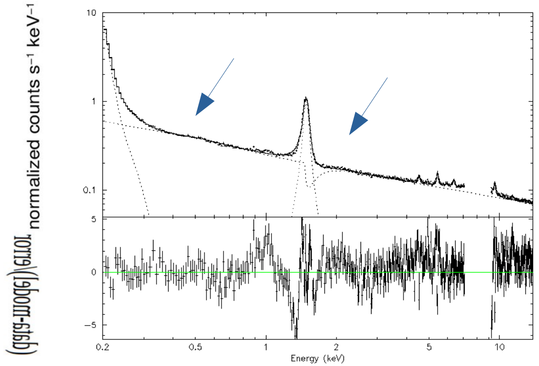
- Most critical for extended sources
- Science: extract spectra in source, background regions and FWC in the source region, fit together
- Best to **fit common model with linked parameters** (naturally accounts for statistical fluctuations in the background spectrum)
- Background is astrophysical + lines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

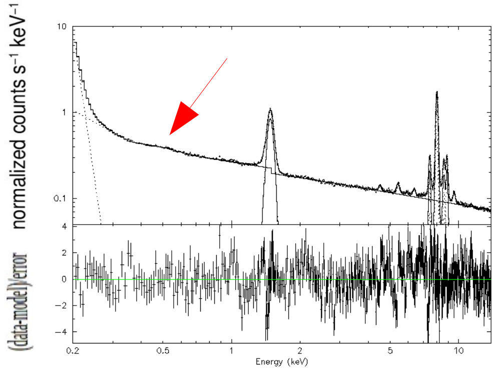
2, Two smedge:

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

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

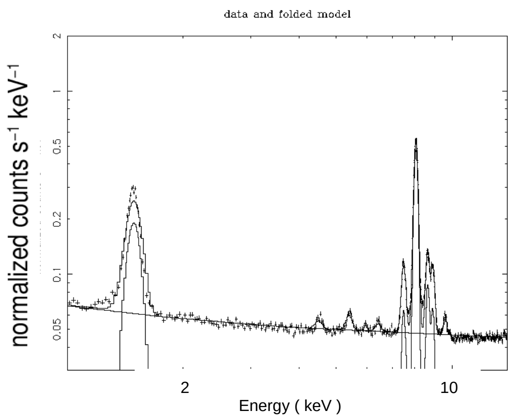
**Small features**

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 !

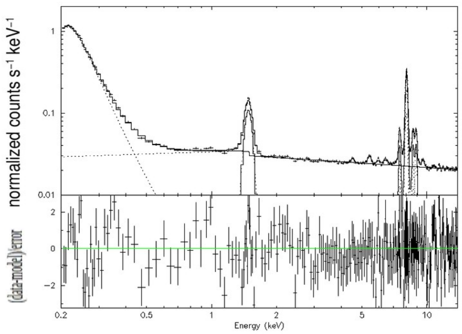
| Element | $K_{\alpha1}$ | $K_{\alpha2}$ | $K_{\beta1}$ | $L_{\alpha1}$ / $L_{\alpha2}$ |
|---|---|---|---|---|
| In the unit of eV | | | | |
| Cu (referrence) | 8,047.78 | 8,027.83 | 8,905.29 | |
| Al | 1,486.70 | 1,486.27 | | |
| Ti | 4,510.84 | 4,504.86 | | |
| Cr | 5,414.72 | 5,405.509 | 5,946.71 | |
| 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.

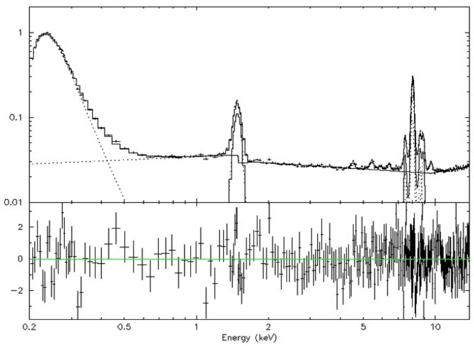
**How to deal with the width :**
For the lines of the same element, the widths were linked.
Eventually, most widths were fixed (Based on the fit results over the full data).

# The analytic models for each pattern of double pixel events

**Pattern=1**



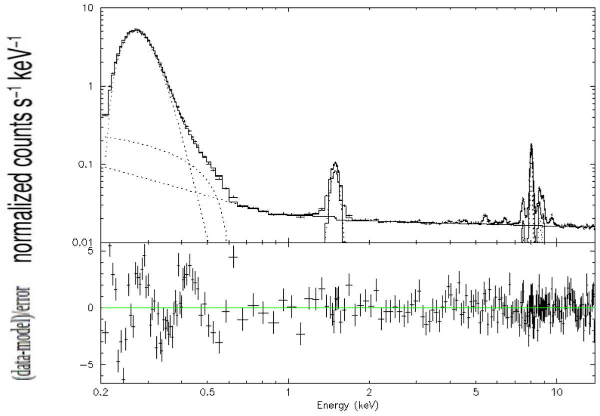

**Pattern=3**




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.

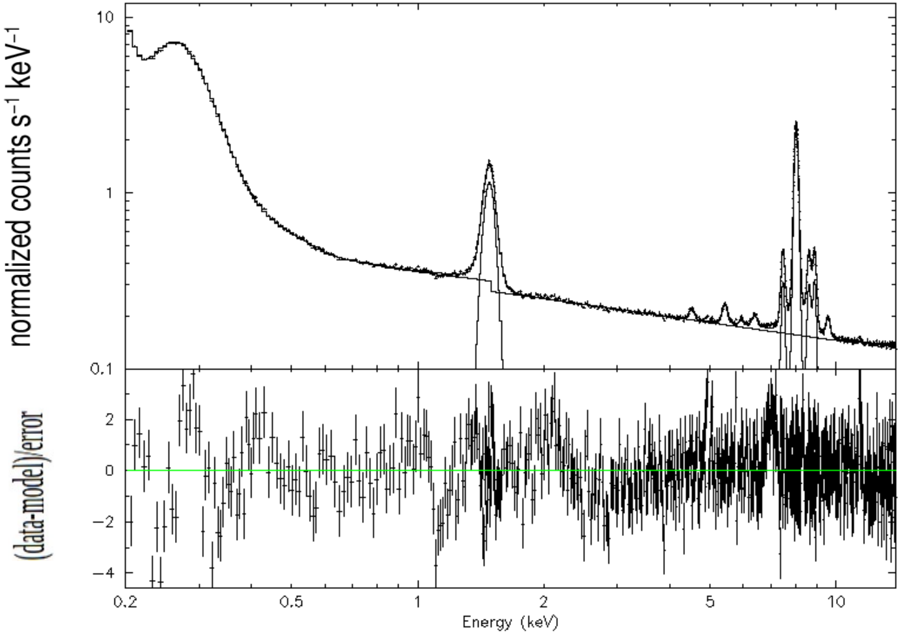
**κ-velocity distribution:**

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

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

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)

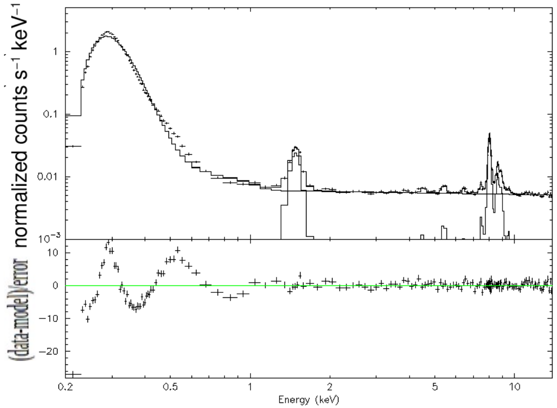
- **The original idea was to fit only the normalization of each component.**

**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 |

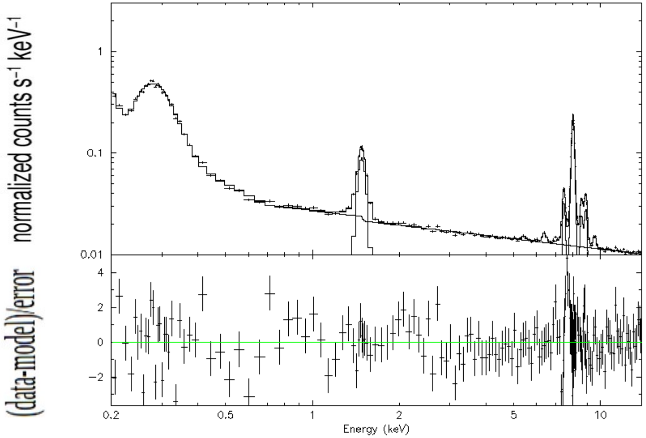
$$C\frac{E'^2}{(1+E'^2/(\kappa-3/2))^{\kappa+1}}$$

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

**7 free parameters**

**And, Lorentz for each fluorescence line.**

***CCD 5 (Pattern<=4)***



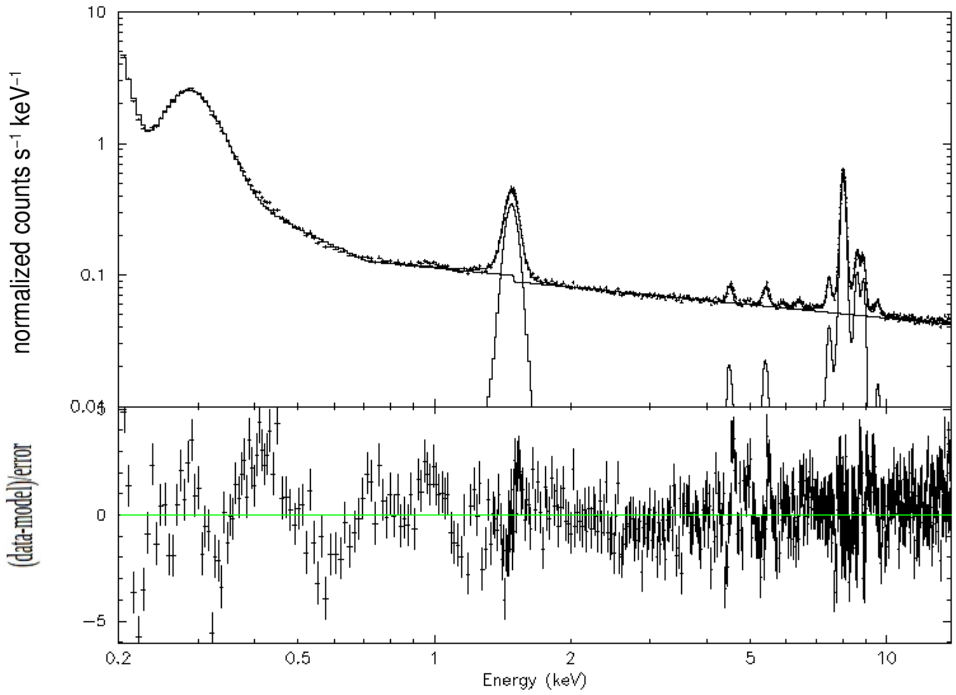
# The problem with the new model

***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

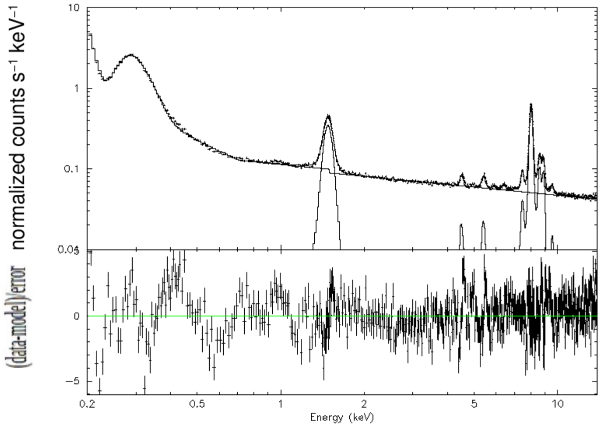
Modified κappa-law model :

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

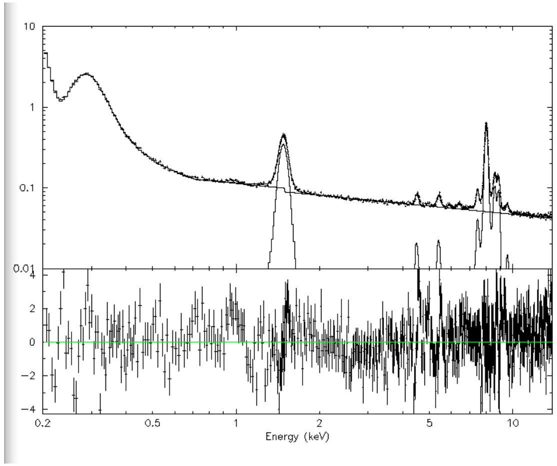
$$E' = (E - E_0)/\Delta E$$

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

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)*

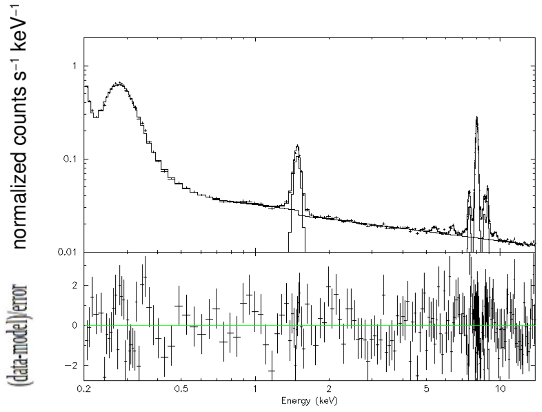
***Same element:*** *Link the norm of the lines of the same elements.*

***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*

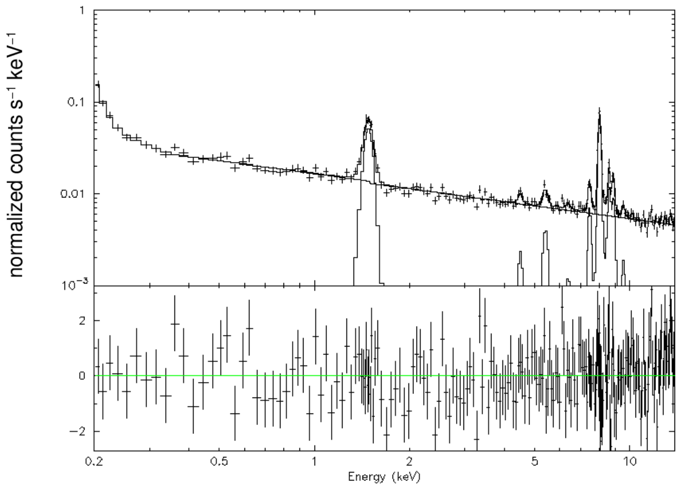
***Same element:*** *Link the width and norm of the lines of the same elements.*

***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

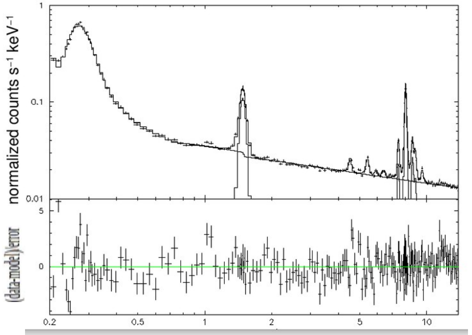


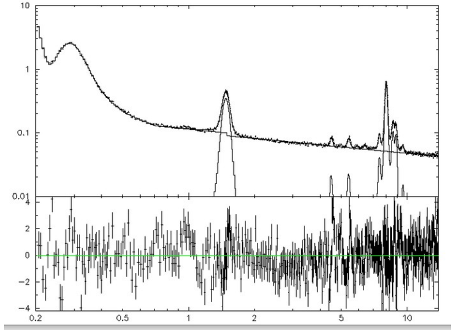
# Comparison with Richard Sturm’s model (Pattern<=4)

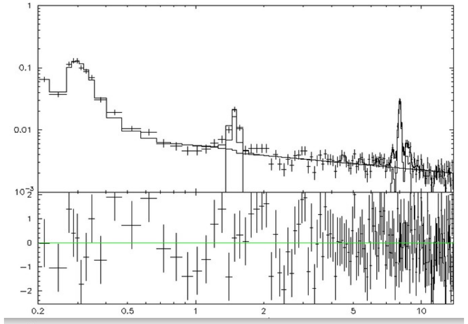
- **The stability** **(Fewer free parameters, more stable).**
- **The accuracy** **(The soft energy band is better fitted ).**

**CCD : (ccd4)** **RawY : (>150)** **Random circle with exposure time ~100 :**

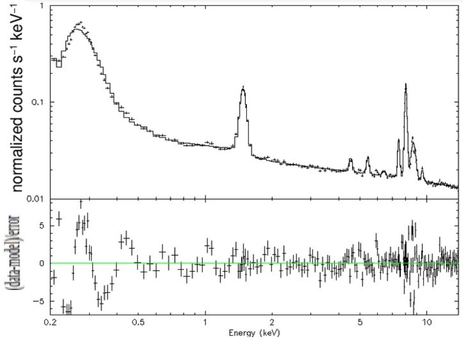
**New :**

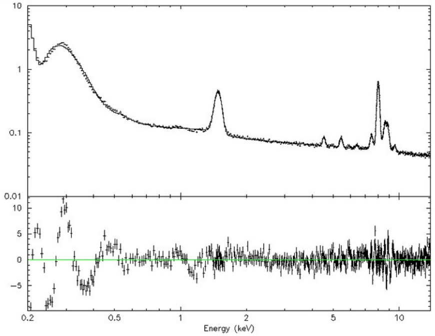


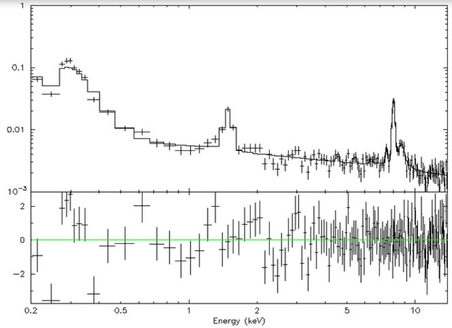





**Richard Sturm**



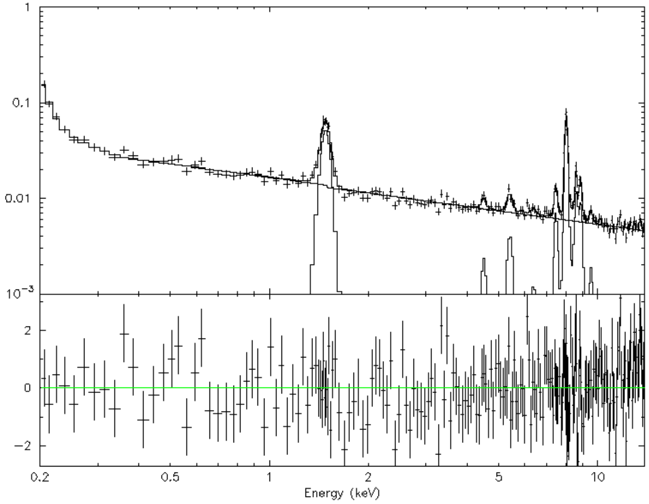
# Comparison with Richard Sturm’s model (Pattern=0)

**Comparable fitting results**

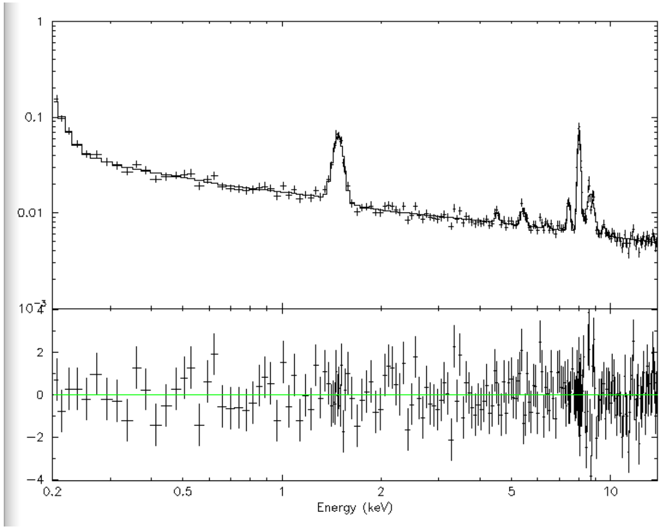
**Fewer free parameters**

**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.