
# Fundamentals of X-ray spectral analysis

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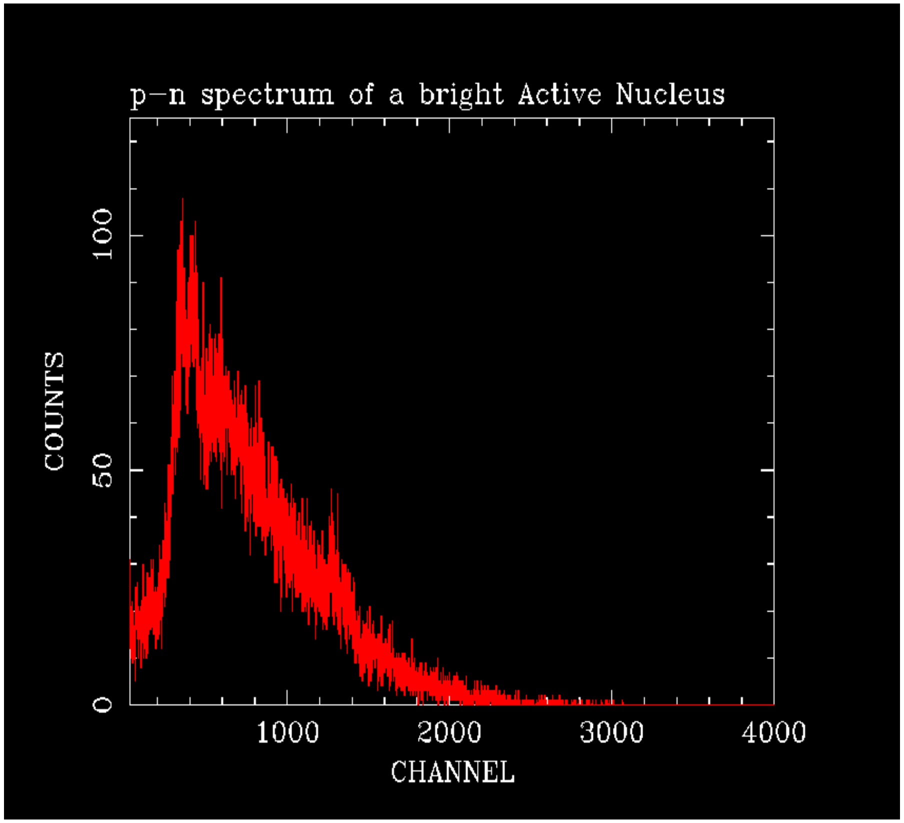
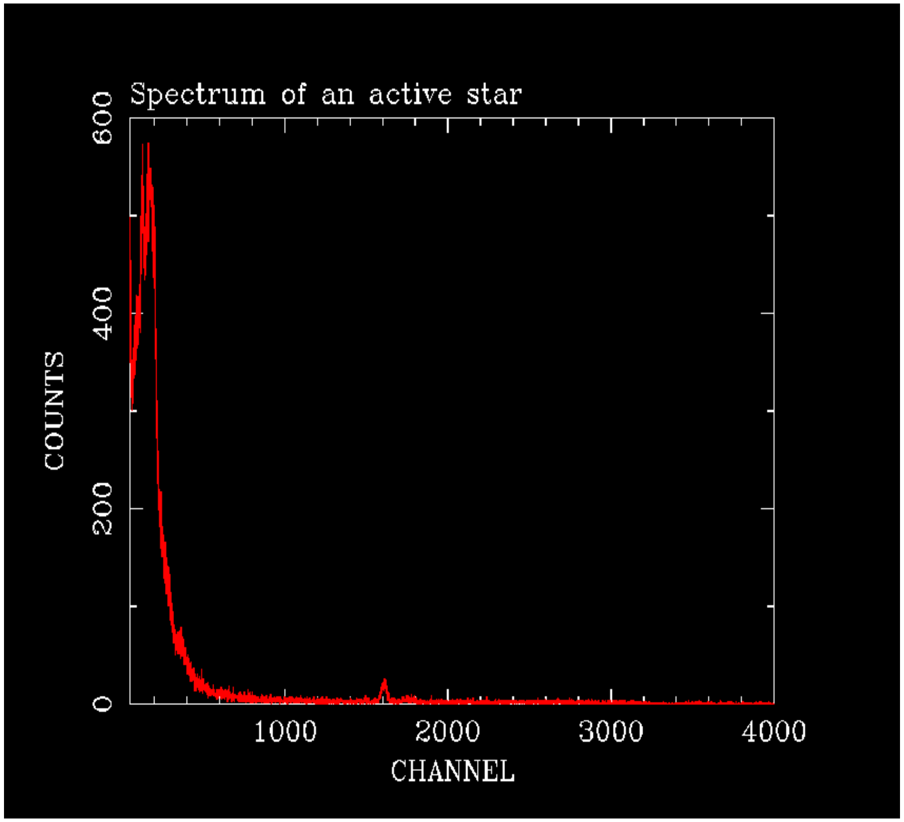
# Transfer function



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# Spectral equation


Observed counts — Exposure time — Transfer function — Intrinsic emission

$$C(\underline{d}, PHA, t) = T(\underline{d}, t) \int dE \int d\underline{r}\; R(\underline{d},PHA,E,\underline{r},t) \times S(E, \underline{r}, t)$$

- Detector coordinates: $\underline{d}$
- Pulse Height: PHA
- Time: $t$
- Sky coordinates: $\underline{r}$
- Energy: $E$

**If R (as usually happens) is not diagonal the equation cannot be inverted. We need an alternative: *assuming* a physical model, *convolving* it with the response, and *comparing* the result with the observed counts, using an appropriate *statistical indicator of good fit quality***

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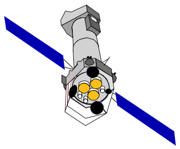
## Forward-folding approach



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# Background



- **Actually two spectra need to be specified:**
  - Source+background spectrum
  - Background spectrum

- **Spectra programs behave in two ways with respect to the background:**
  - *either* subtract the background spectrum *[B(E)]* from the source+background spectrum *[S(E)], to get a background-subtracted spectrum [C(E)]*
    - $C(E)=S(E)/t_{S(E)}-b_{S(E)}/b_{B(E)}\bullet B(E)/t_{B(E)}$
  - *or require indipendent models to be simultaneously fit to S(E) and B(E)*
  - ***we'll follow the former approach***

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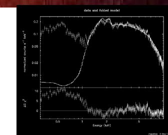
# How does it work in practice?

[2]including start values, upper/lower boundaries, variation steps for all parameters

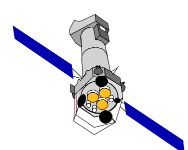
[1]see later slide

Load spectra and response files → Choose[1] statistics → Define model[2] → Fit the model[3] → Good fit?

NO → Define model[2]

YES → Publish, glory and fortune

[3]this means: vary all the model parameters within the defined boundaries according to the defined step, and determine the set of parameters values, which minimizes the statistical estimator



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# Caveats on the spectra

- **In order to compare the model with the observed spectra a statistical test needs to be used.**
  - if one can approximate the distribution in each spectral channel as a Gaussian (counts/bin > 25), the easy-to-implement, easy-to-judge $\chi^2$ test may be used
  - if data have a lower S/N ratio, either binning, or use different statistics (Cash, Bayesian methods etc.)

- **A *sampling theorem* applies in the energy domain. Even in the ideal case of an infinite S/N ratio spectrum, a *Nyquist frequency* in the energy space exists ($\propto$ 1/E), which dictates the optimal binning of the spectrum, as a function of the instrumental response**

- **Although the bulk of the photons are in the continuum, most of the physics (ionisation, chemistry, abundance, geometry, general relativity) is in the lines**

- **The S/N ratio determines what type of science can be done: ~$10^2$ counts $\Rightarrow$ ratio between different energy bands; ~$10^3$ counts $\Rightarrow$ science of the continuum; $10^4$ counts $\Rightarrow$ true physics**

- **Joint fit of different instrument/orders is highly preferred to attempts to sum spectra of different instruments/camerasm unless in the low-counts regime:**
  - cross-systematic uncertainties difficult to recover on summed spectra
  - order mixing degrades the instrument performance

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# Fitting in low counts regime

A few hints for the spectral fitting - low S/N spectra:

- *Can I combine RGS1 and RGS1 or RGS1 and RGS2?*

  Yes: bin the data in $\lambda$ space and use the SAS task `rgscombine`

- *Can I combine different orders ?*

  Not recommended, one loses resolution. Fit simultaneously

- *Should I use 'total' or 'net' spectrum ?*

  For low statistics is better to use 'total' and 'background'

- *Should I rebin my spectra?*

  - The $\chi^2$ goodness-of-fit test requires that the count distribution in each spectra channel is Gaussian
  - In the low-count regime this implies spectral rebinning …
  - … however, spectral rebinning entails losing spectral resolution

Solution: use different statistics (C-statistics …)