

# X-Ray Data Analysis

- Photons in versus data out
- Response matrix
- Background
- Source detection
- Spectral fitting

# Photons in versus Data out

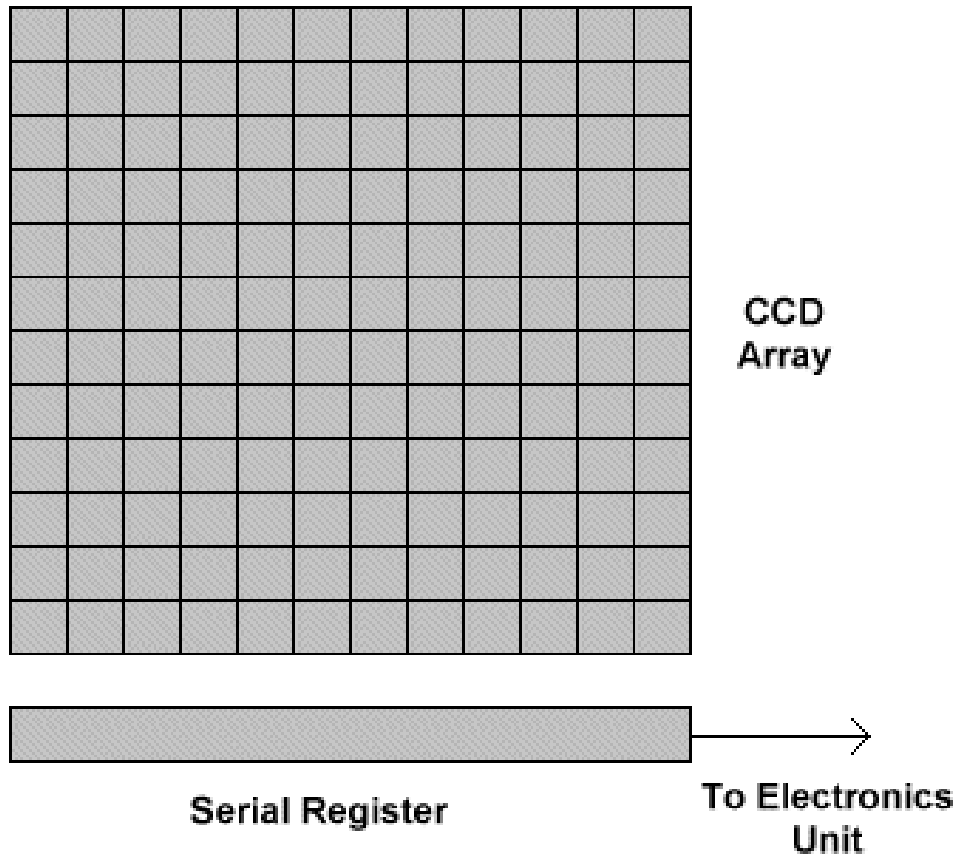


Detector measures certain properties of a photon  
(energy, time of arrival, position of arrival)

and then outputs a number of bits of information  
describing the photon

The photon properties are determined from the detector  
output by applying a calibration

# CCD Example



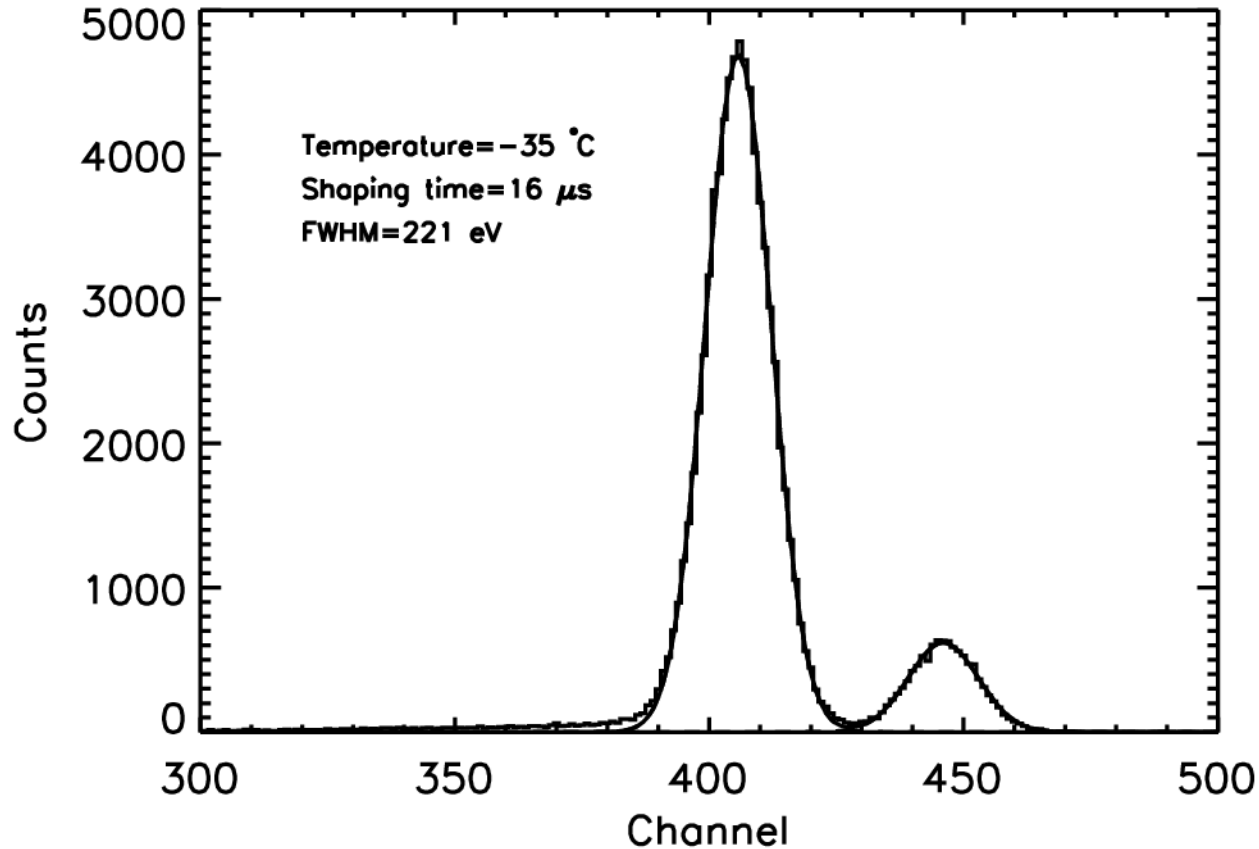
At regular intervals (the frame time), the contents of the active region is transferred to the frame store, then the charge in each pixel is measured using an A/D converter. We get out a digital value (the pulse height amplitude = PHA) for each pixel representing the charge in that pixel.

X-rays produce pixels or clusters of pixels with PHA above the noise level.

# CCD Example

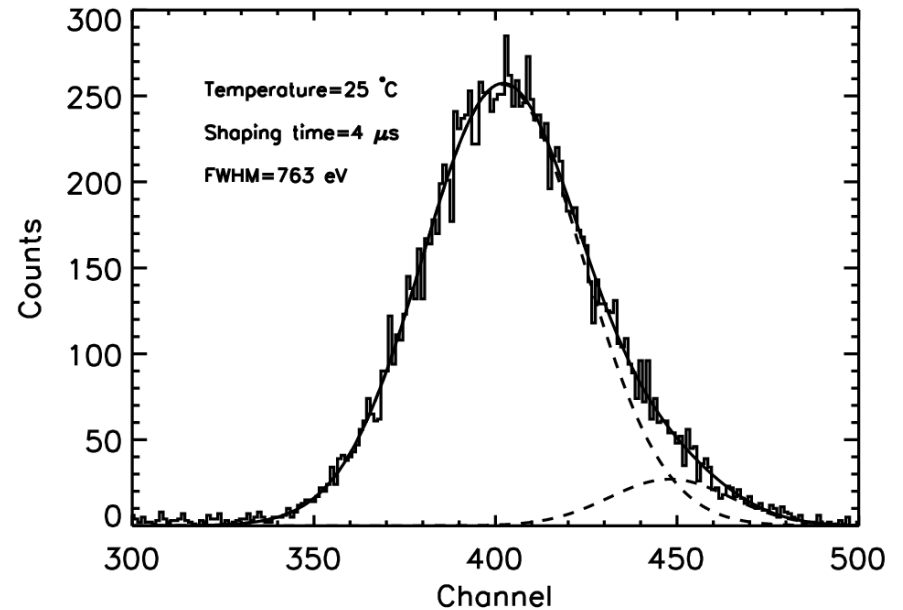
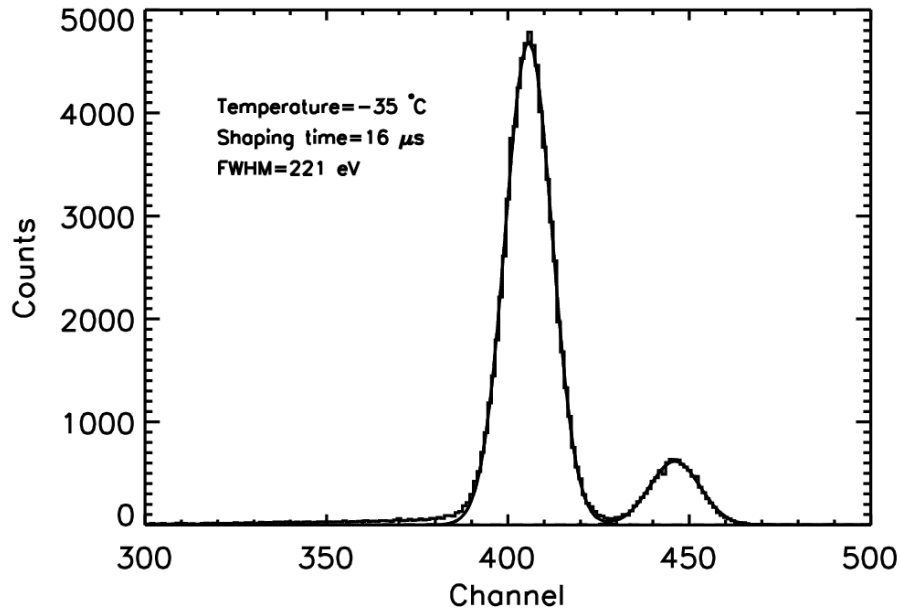
- Time of event?
  - Time at which the charge was transferred to the frame store
  - Only calibration needed is accurate satellite clock
- Energy of event?
  - Sum of PHA in pixels in cluster corresponds to an individual X-ray
  - Need energy calibration to convert PHA value to an energy
- Position of event?
  - Position of hit pixel or centroid of cluster
  - Need to know size of CCD to convert to physical position
  - Need to know focal length of telescope, pointing of telescope, and relative telescope/detector position to convert to position on the sky

# Energy Calibration



Shine a monochromatic X-ray beam on the detector, then measure the response. Use several different energies to find energy versus channel conversion. Also, need to know shape of response and efficiency at each energy.

# Energy Calibration



Detector response will, in general, also depend on environmental factors such as temperature.

# Response Matrix

$$\vec{c} = R \vec{s}$$
$$\begin{pmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_n \end{pmatrix} = \begin{pmatrix} R_{1,1} & R_{1,2} & R_{1,3} & \cdots & R_{1,n-1} \\ R_{2,1} & R_{2,2} & R_{2,3} & \cdots & R_{2,n-1} \\ R_{3,1} & R_{3,2} & R_{3,3} & \cdots & R_{3,n-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ R_{n,1} & R_{n,2} & R_{n,3} & \cdots & R_{n,n} \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ \vdots \\ s_n \end{pmatrix}$$

s = physical spectrum, flux versus energy

R = response matrix

c = expected detector counts versus channel

For Xspec, the efficiency versus energy is described by the “Auxiliary Response File” (ARF) which gives telescope area  $\times$  filter efficiency  $\times$  detector quantum efficiency versus energy while the detector response is described by the “Redistribution Matrix File” (RMF). The response is the product of the two.

# Data Products

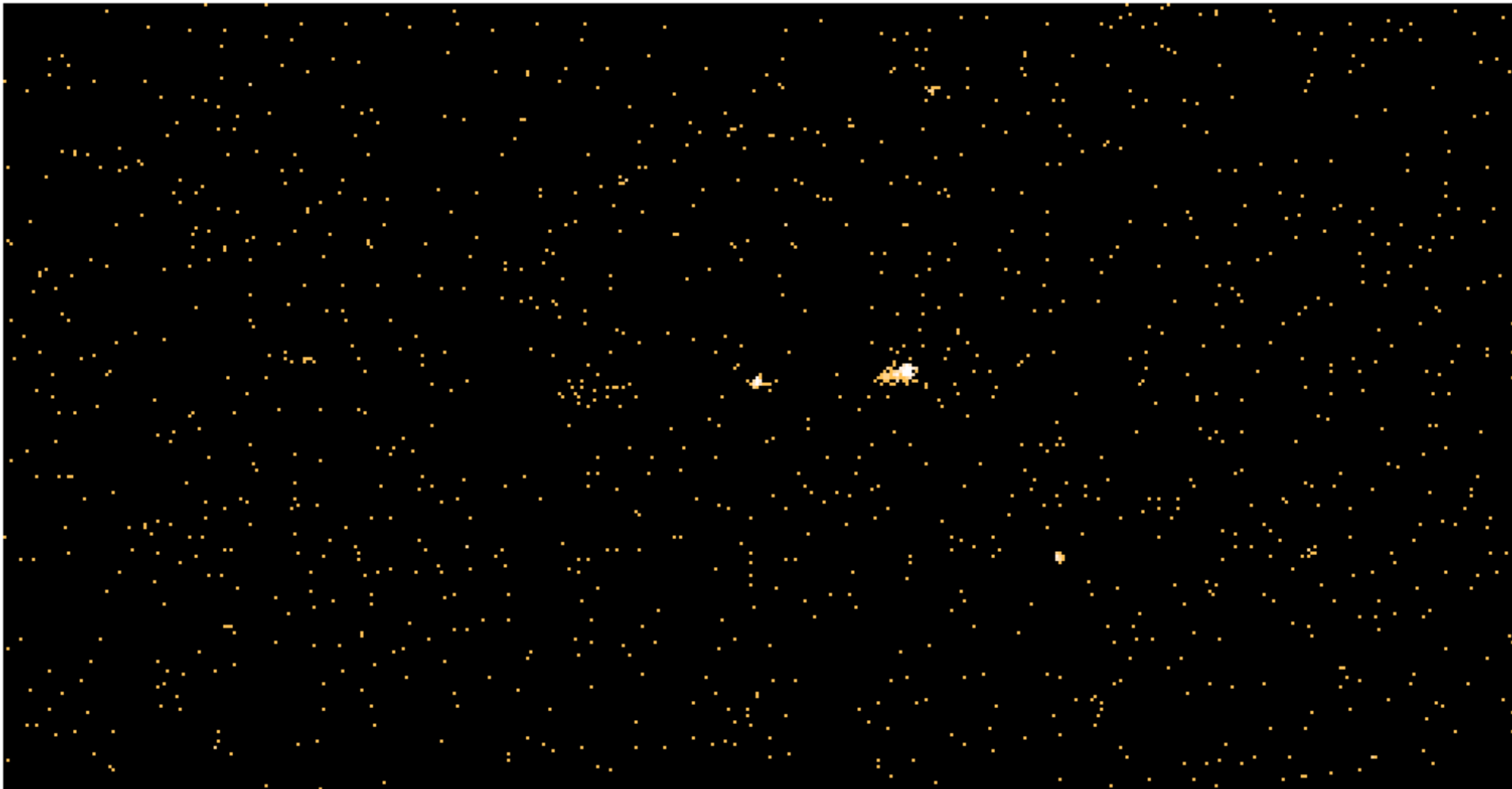
- Photon list
  - Pulse height amplitude (PHA), arrival time, position, event grade, ...
- Auxiliary information
  - Telescope pointing direction, detector position, satellite location, detector temperature, particle rates, ...



# Image Analysis

- Use photon list to create image – a 2-d histogram of counts on the sky (requires each photon to be tagged with sky coordinates)
- Source detection - simplest technique is simply to examine the image visually and find sources.
- For each source, its position can be found by calculating the centroid of the photons in the source.
- One should also estimate the significance of each source detection.

# X-Ray Image of XTE J1550-564

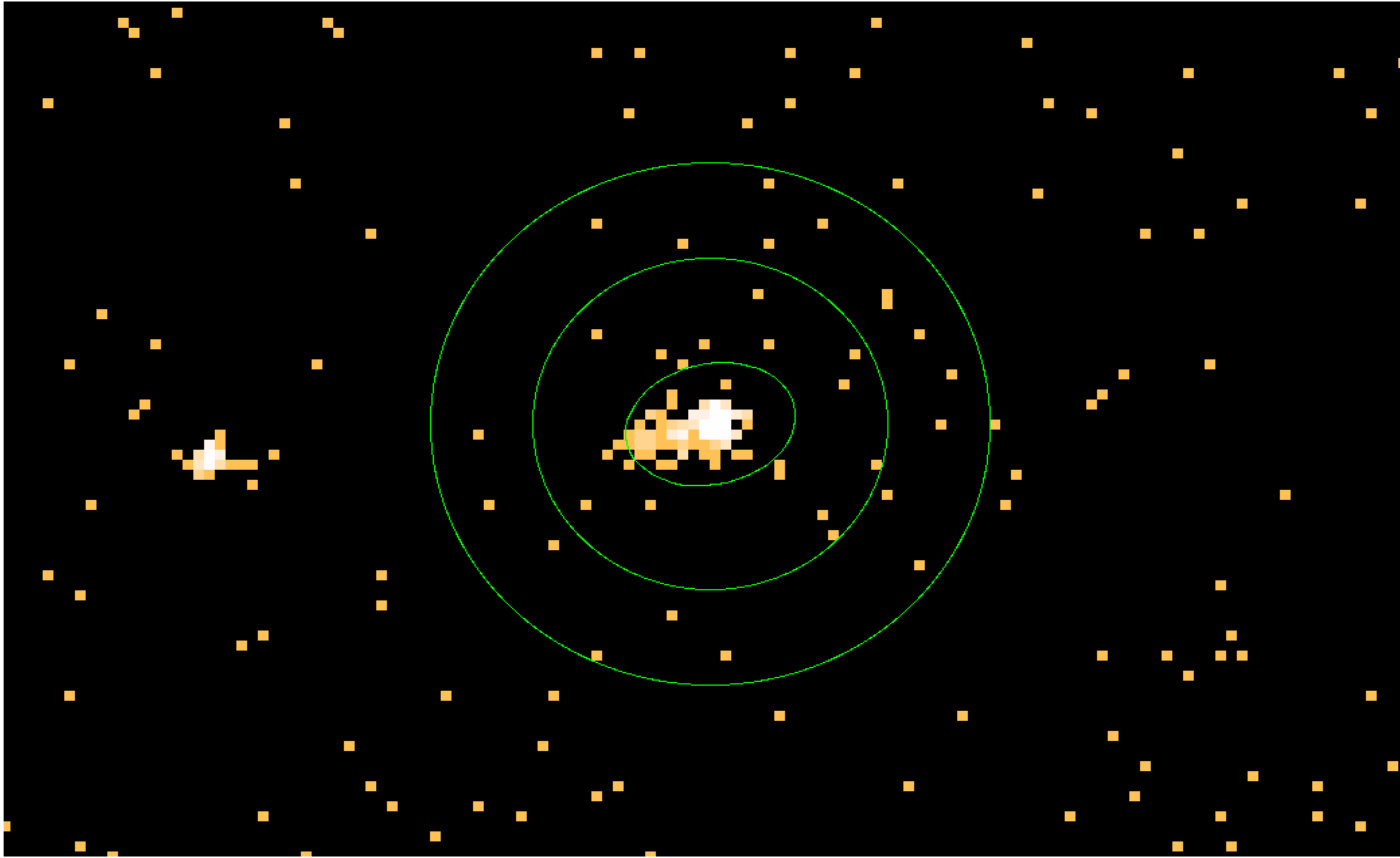


Chandra image of Galactic black hole candidate XTE J1550-564. BH and two jets appear in image.

# Spectral Analysis

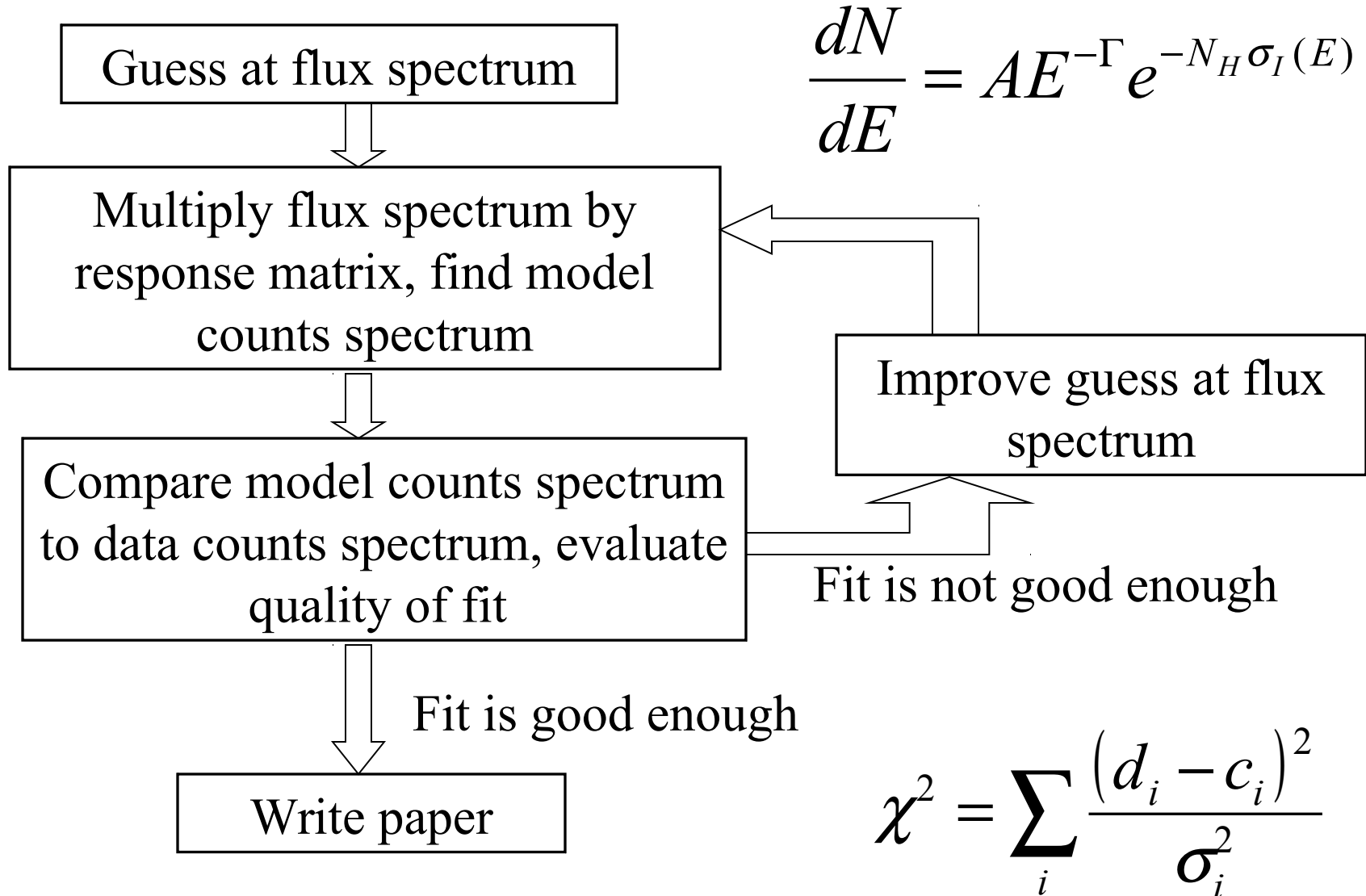
- Need to extract photons for each source and also an estimate of background.
- Need to have a model (response matrix) of the detector response to relate proposed physical source spectra to the counts in the detector.

# Source and Background



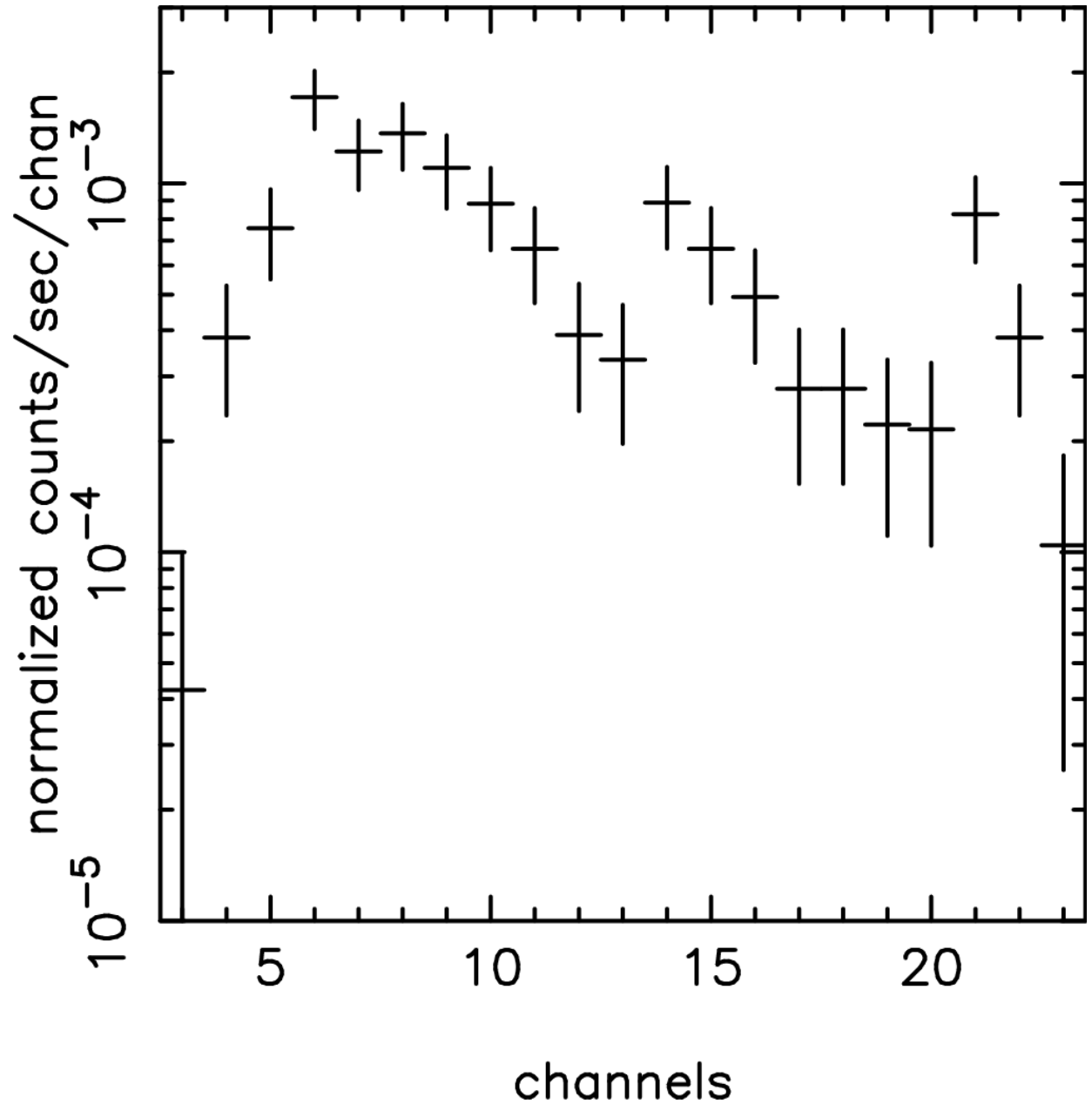
Extract source counts from inner ellipse. Extract background counts from outer annulus.

# Spectral Analysis



# Spectral Analysis

Raw counts  
in detector  
channels

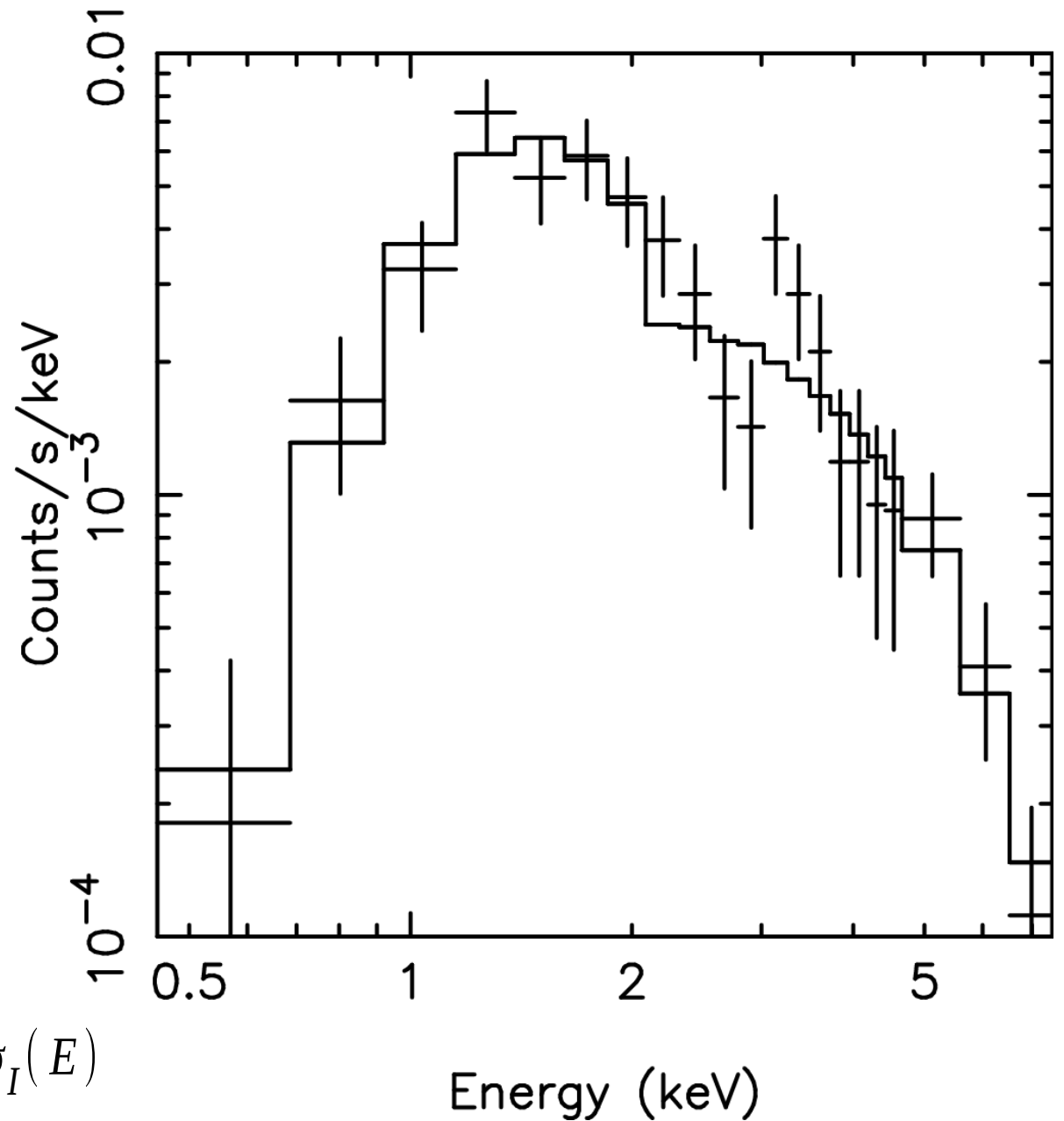


# Spectral Analysis

Channels to energies

Model is power-law multiplied by absorption

$$\frac{dN}{dE} = AE^{-\Gamma} e^{-N_H \sigma_I(E)}$$

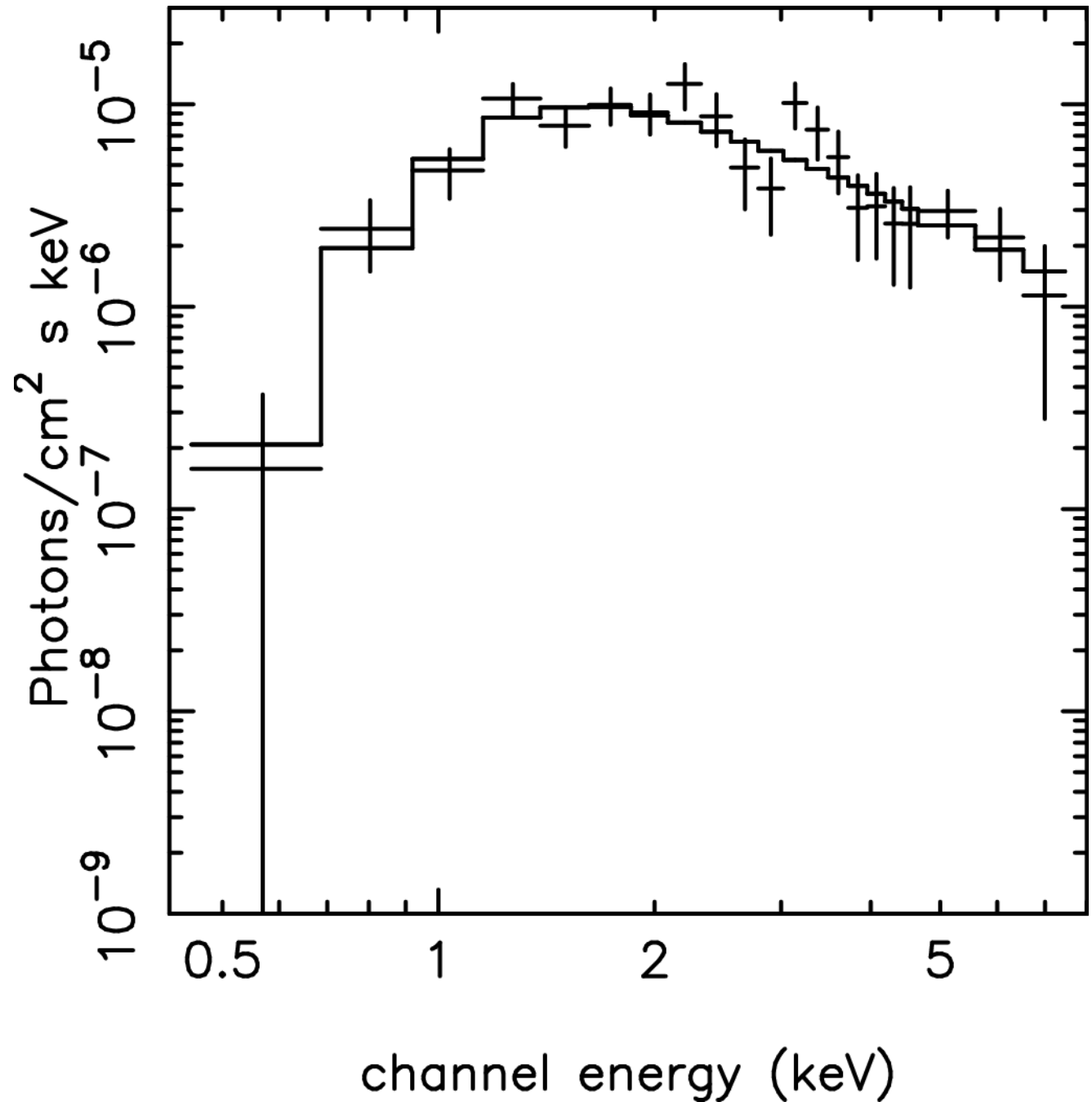


# Spectral Analysis

Counts converted to incident photons.

No dependence of plotted quantities on instrument.

Note 'unfolding' does depend on model used.





# Temporal Analysis

- Create light curve for given source in given energy band
- Search for pulsations and other timing signals

# Homework

- We will do data analysis on Wednesday (8/31)
- Try to download and install LHEASOFT.
- Read the paper "Energy Spectra of the Soft X-Ray Diffuse Emission in Fourteen Fields Observed with Suzaku" by Tomotaka Yoshino et al. (2009) from <http://adsabs.harvard.edu/abs/2009PASJ...61..805Y>.
- Be sure to bring your laptop to class.