X-Ray Data Analysis

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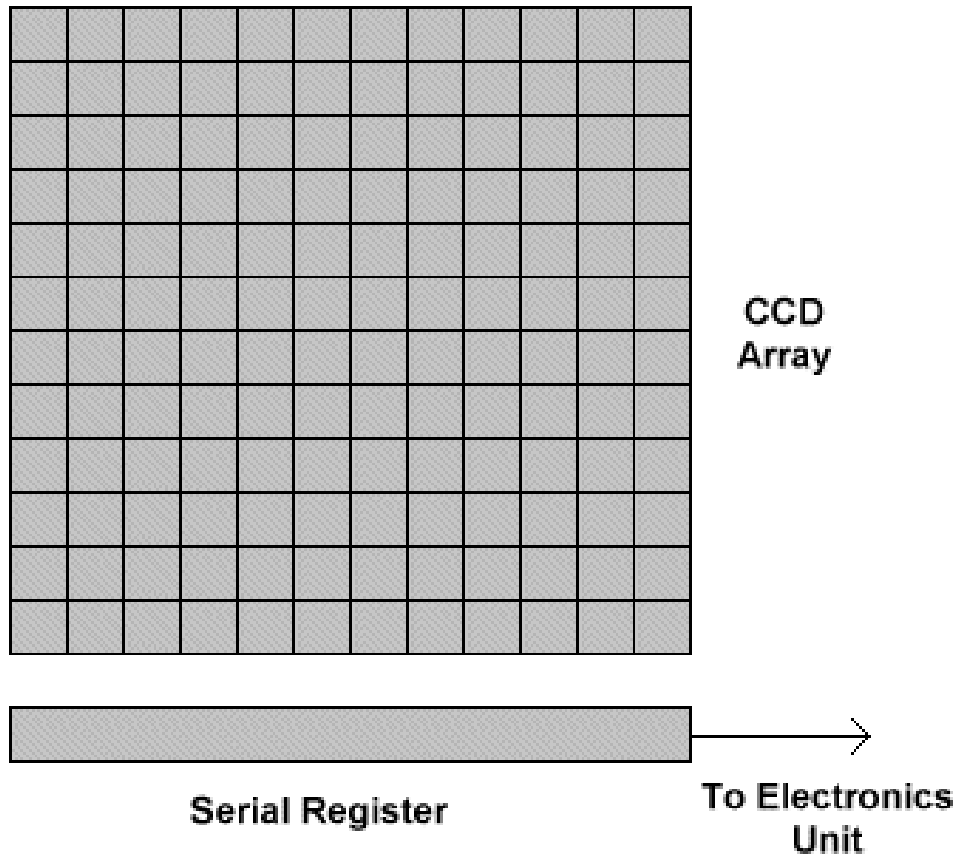
Photons in versus Data out

X-ray

Detector

Data

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

CCD Array

Serial Register

To Electronics Unit

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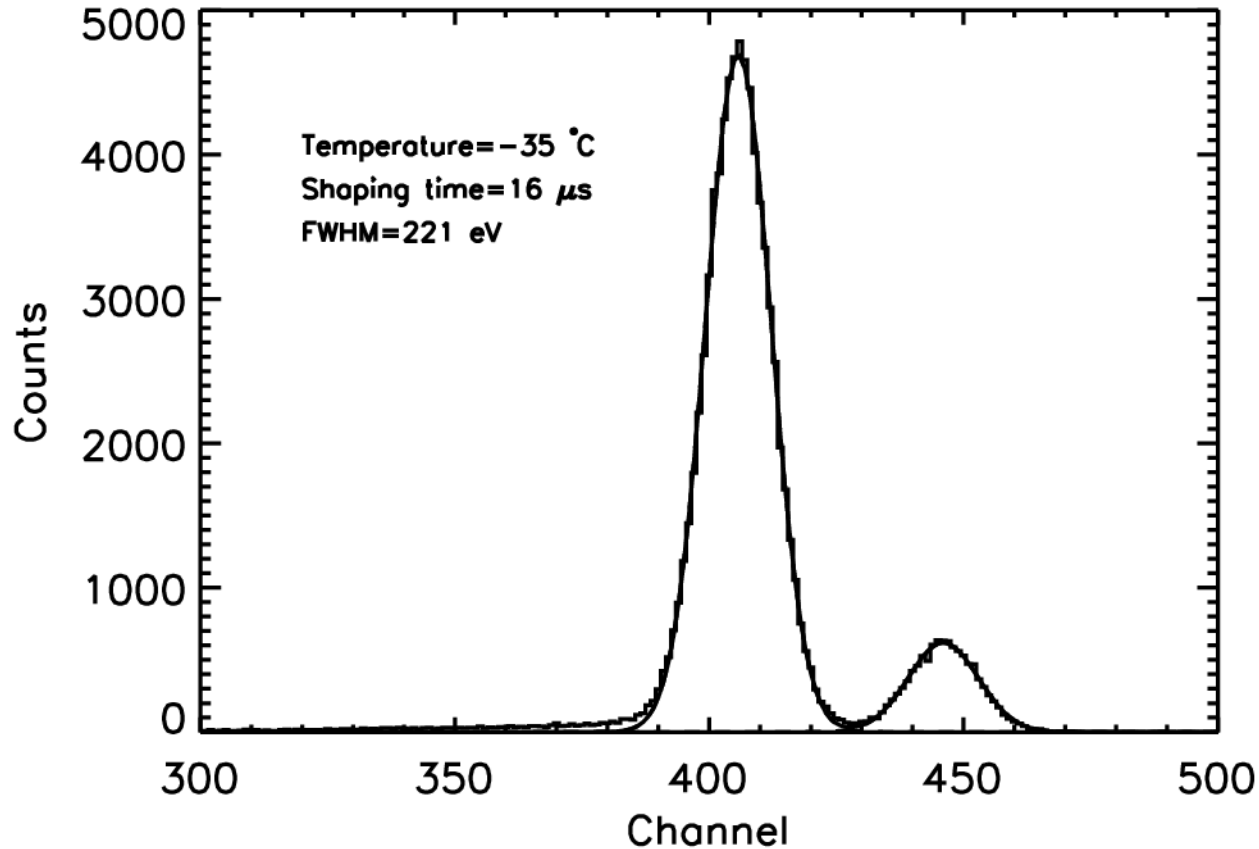
Shine a monochromatic X-ray beam on the detector, then measure the response. Use several different energies to find energy versus channel conversion. Also, need to know shape of response and efficiency at each energy.

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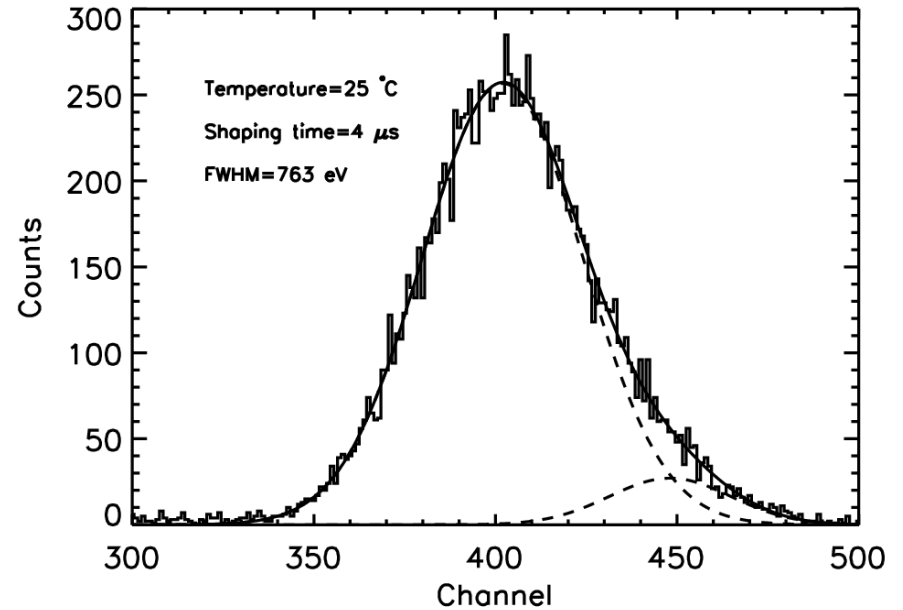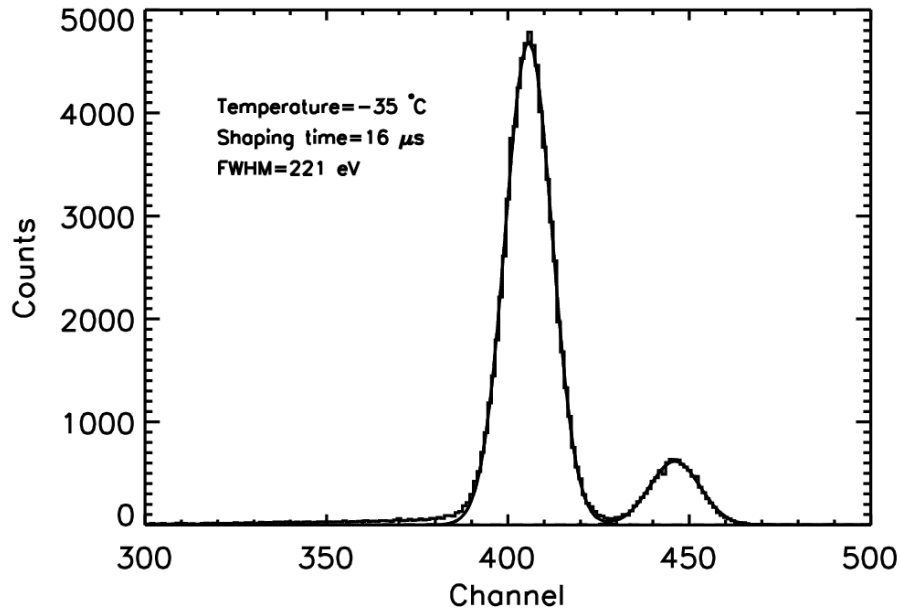
Detector response will, in general, also depend on environmental factors such as temperature.

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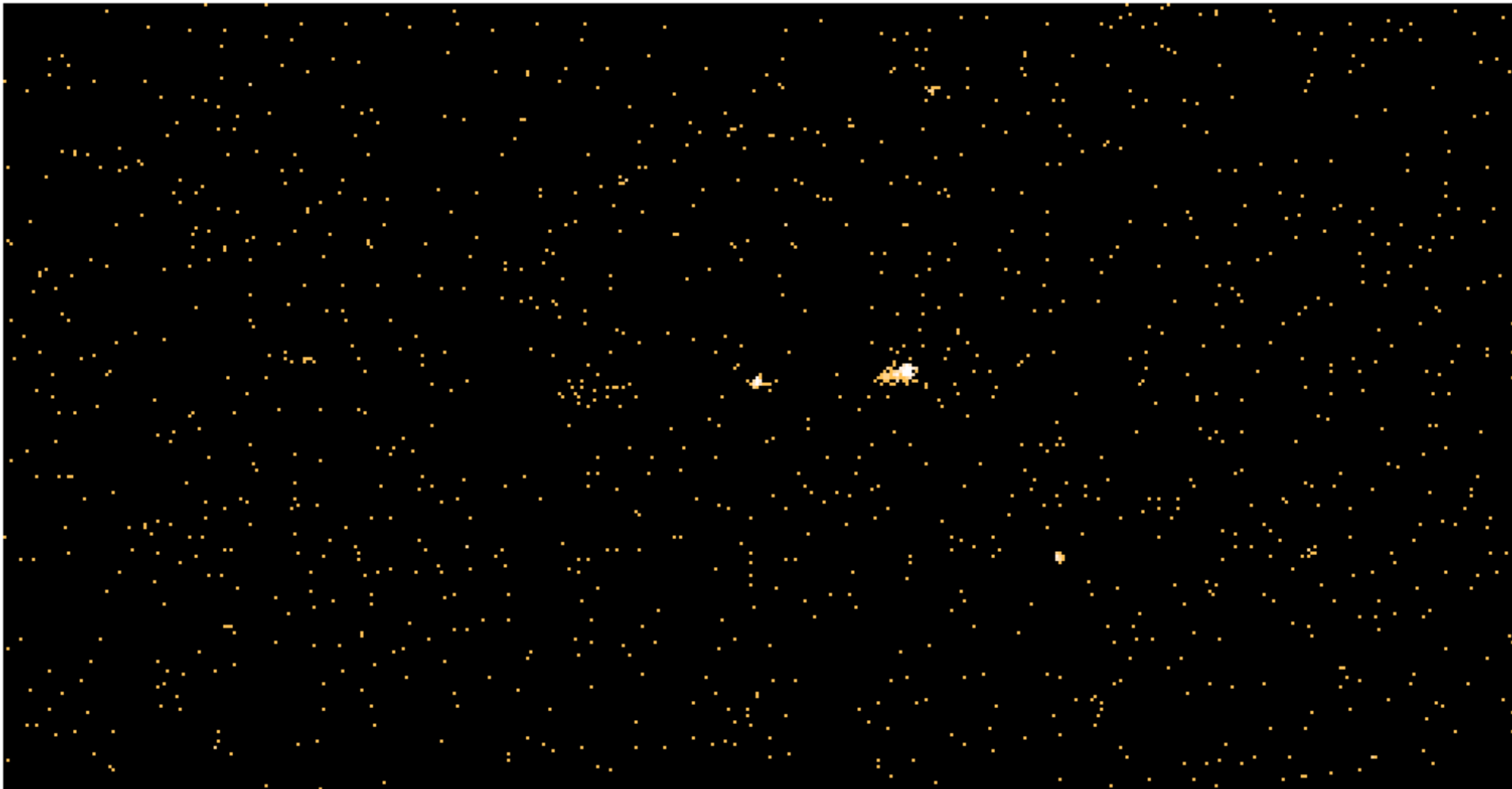
Chandra image of Galactic black hole candidate XTE J1550-564. BH and two jets appear in image.
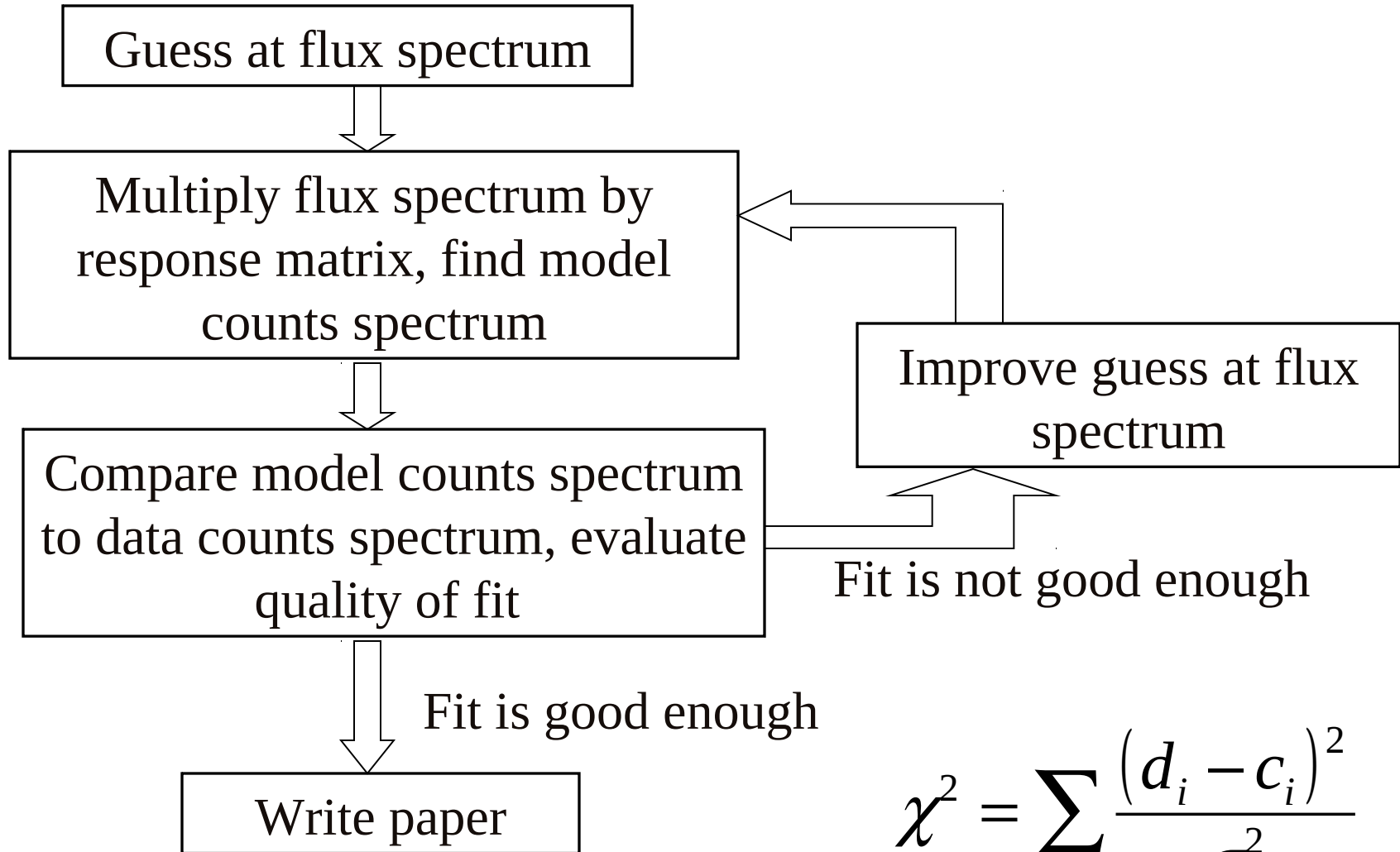
Spectral Analysis

- 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
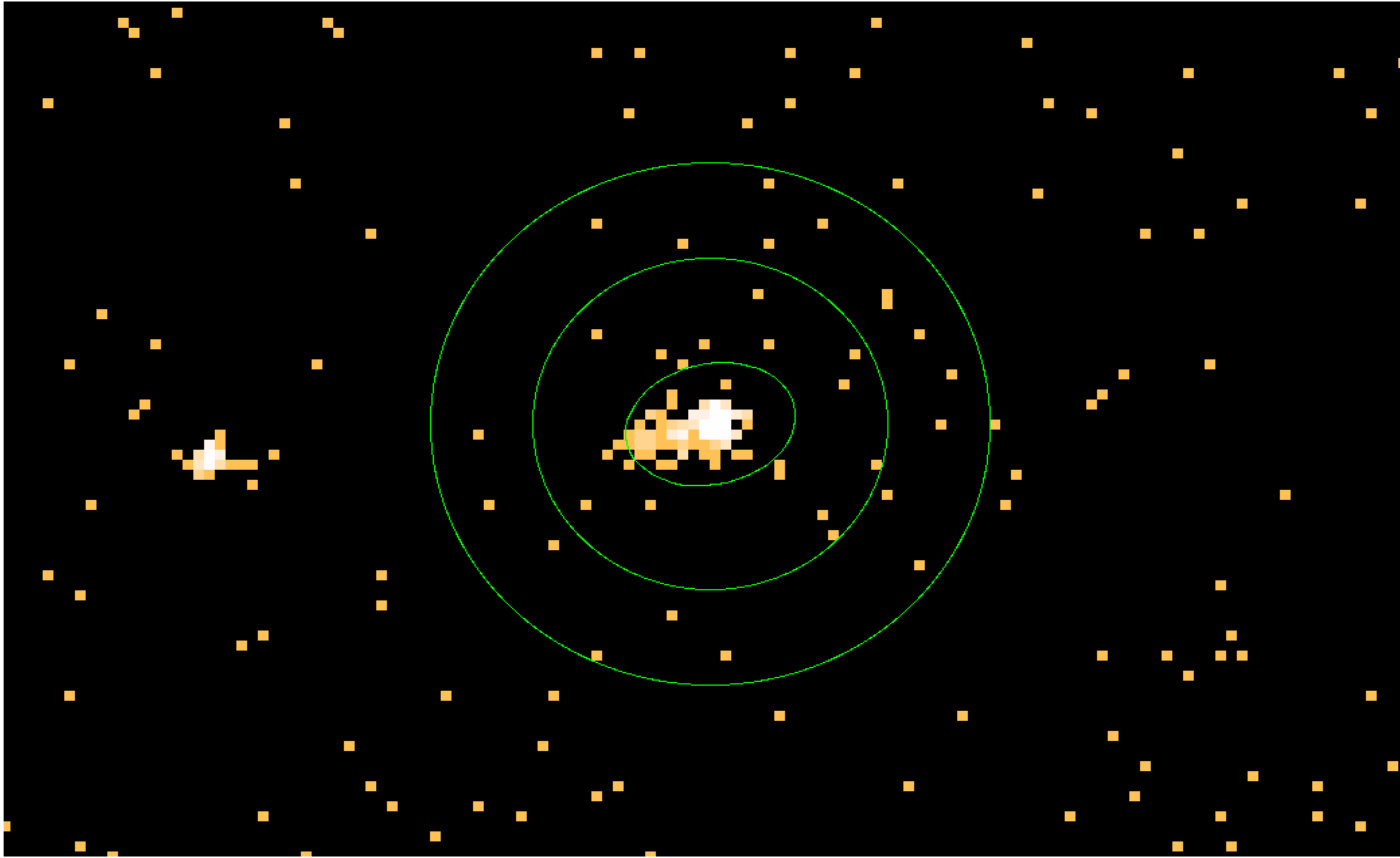
Extract source counts from inner ellipse. Extract background counts from outer annulus.
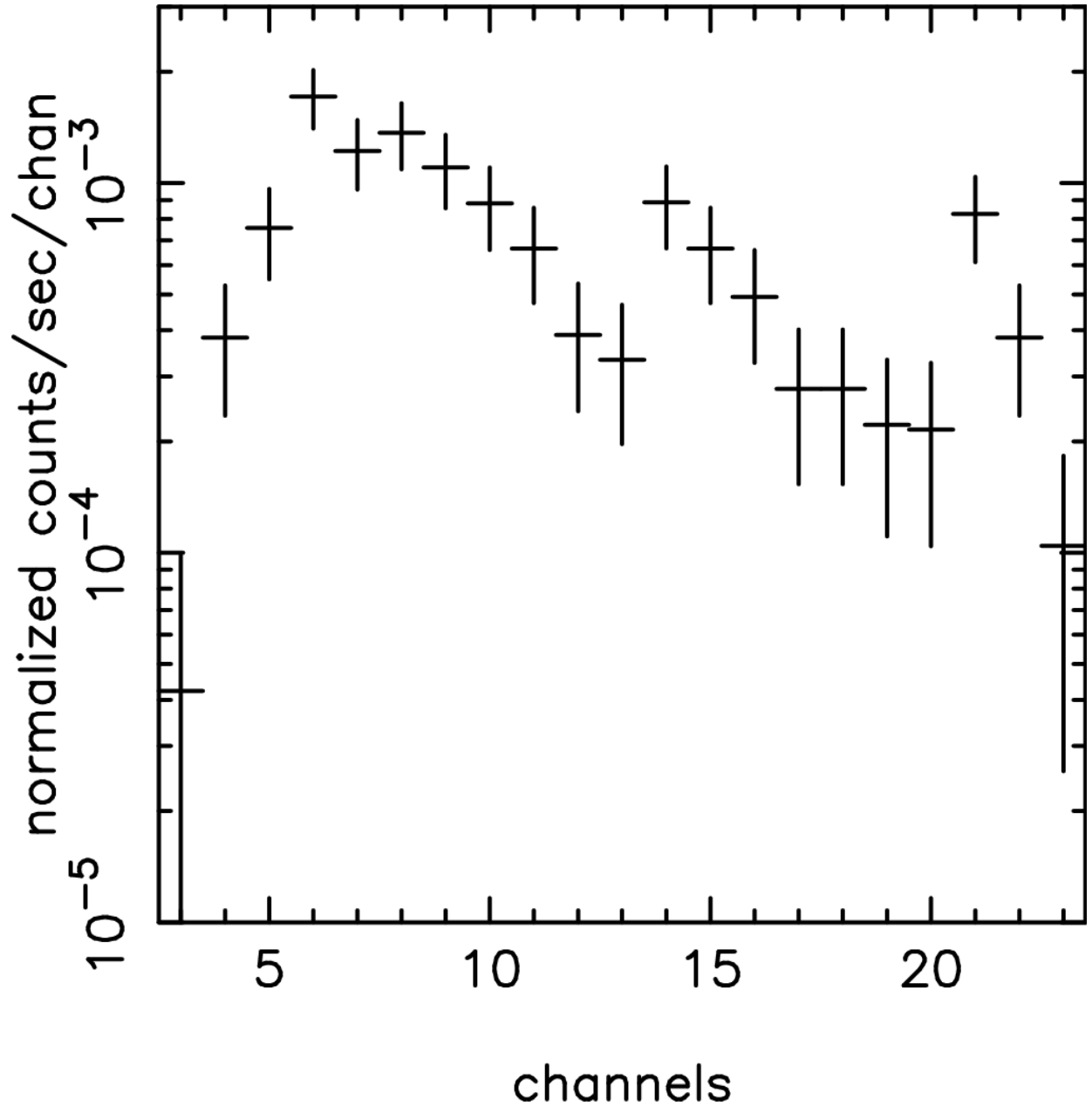
Spectral Analysis

Guess at flux spectrum

Multiply flux spectrum by response matrix, find model counts spectrum

Compare model counts spectrum to data counts spectrum, evaluate quality of fit

Improve guess at flux spectrum

Fit is not good enough

Fit is good enough

Write paper

$$\chi^2 = \sum_i \frac{(d_i - c_i)^2}{\sigma_i^2}$$

Spectral Analysis
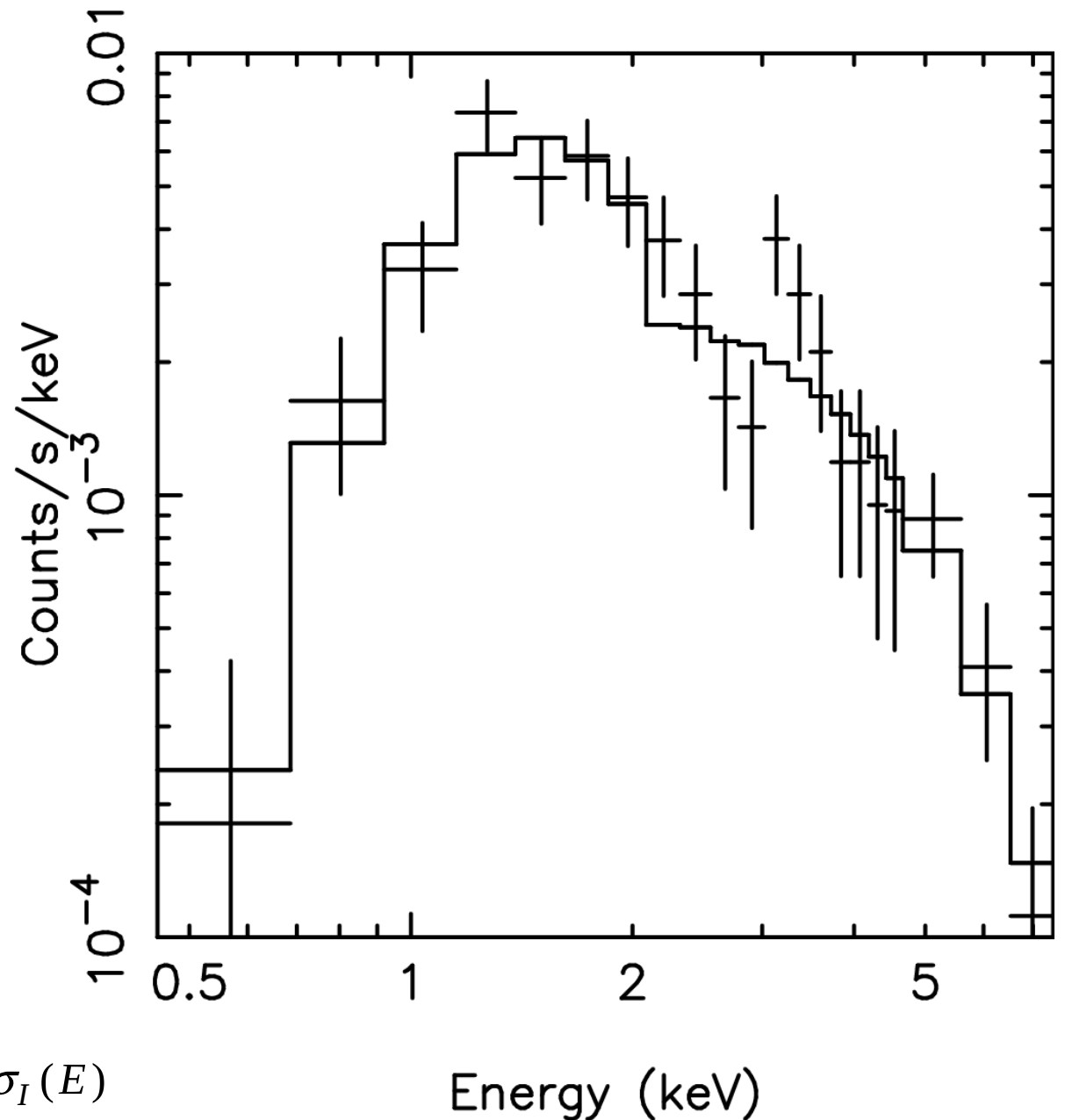

Raw counts in detector channels
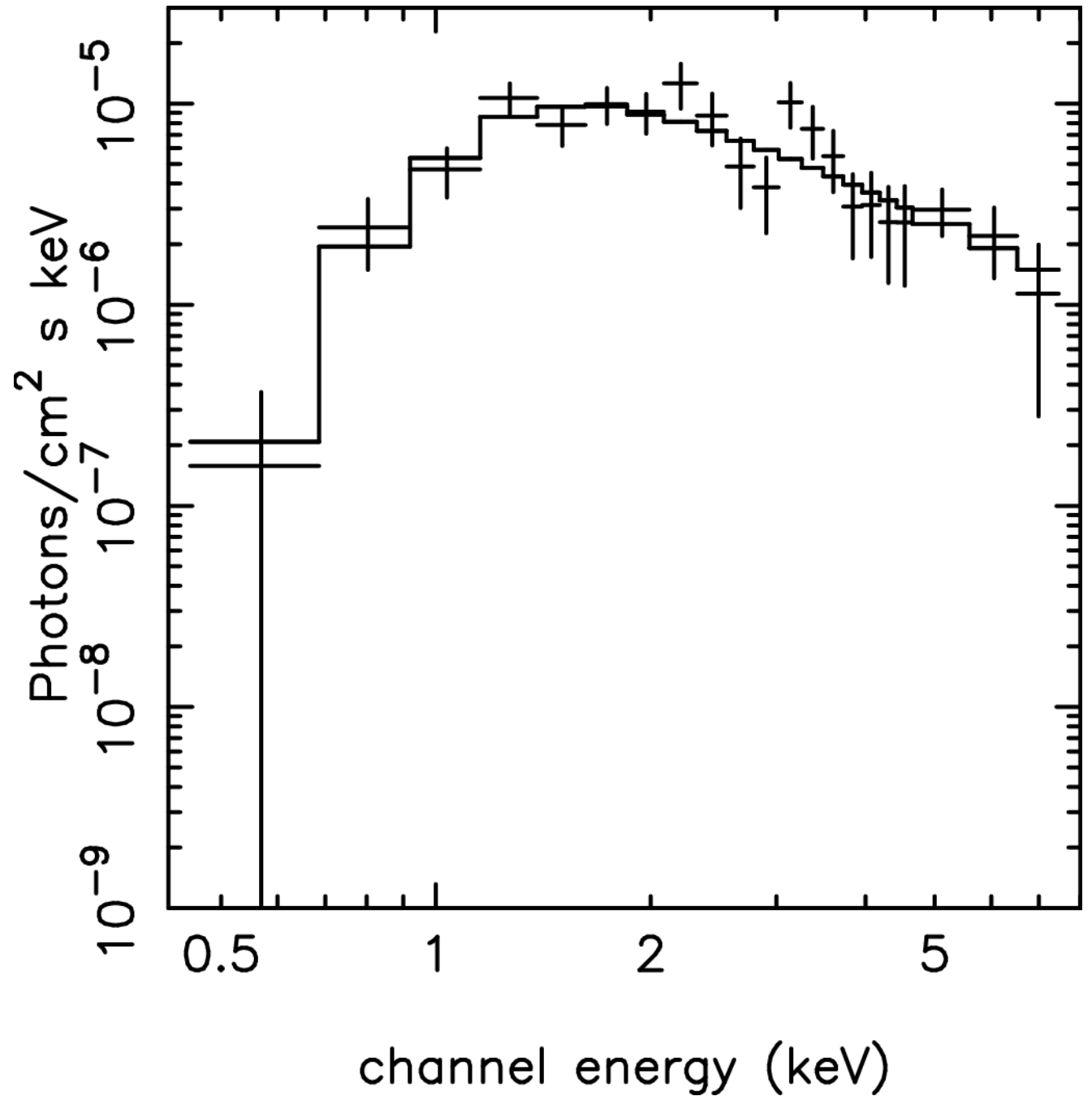
Spectral Analysis

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

Temporal Analysis

- Create light curve for given source in given energy band

- Search for pulsations and other timing signals