Astro 193 : Data II
Feb 2

• Follow-up
  • Data resources
  • errors in astronomy are heteroskedastic
  • density plots with outliers

• Detectors

• The fundamental equation of astronomical data
Data resources
Tai Ding’s plot of magnitude vs errors

Variance is usually not constant across data in astronomy problems. Be careful with applying standard least-squares fits algorithms, because they tend to assume constant variance.
Yutong’s question: how to depict large numbers of points?
1D: Box/Whisker plots with outliers

- □ → FAROUTLIER
  - Far Upper fence
  - 3(IQR) above 75th percentile

- □ → OUTLIER
  - Upper fence
  - 1.5(IQR) above 75th percentile

- MAX

- Q3 (75th percentile)
- MEAN
- MEDIAN
- Q1 (25th percentile)
- MIN

- Lower fence
  - 1.5(IQR) below 25th percentile

1D: Box/Whisker plots with outliers

Debosscher et al. 2007, A&A 475, 1159, Fig 3
2D: Contour plots with outliers

Dhital et al. 2010, AJ 139, 2566
2D: density plots with outliers

Bar Likelihood ($p_{bar}$)

http://docs.flowjo.com/wp-content/uploads/sites/5/2013/03/
http://blog.galaxyzoo.org/category/paper/
http://www.astroml.org/book_figures/chapter1/fig_S82_scatter_contour.html
Detectors
The fundamental equation of astronomical data

How incoming flux is distorted

\[ \lambda(x', E', t'; \theta) = \int \int \int dt \ dE \ dx \ f(x, E, t; \theta) \]
\[ A(E; x', t, f) \]
\[ P(x, x'; E, t, f) \]
\[ R(E, E'; x', t, x) \]
\[ \Delta(t, t') \]

What is observed?

\[ Y(x', E', t'; \theta) = \text{Poisson}(\lambda) \]
\[ Y(x', E', t'; \theta) = \text{Normal}(\lambda, \sigma^2) \]
\[ \lambda(x',E,t';\theta) = \int \int dt \, dE \, dx \, f(x,E,t;\theta) \, A(E; \, x',t,f) \, P(x,x'; \, E,t,f) \, R(E,E'; \, x',t,x) \, \Delta(t,t') \]

\[ f(x,E,t;\theta) \text{ [ph s}^{-1} \text{ cm}^{-2}] \]

\[ f_{v,\lambda}(x,E,t;\theta) \text{ [ergs s}^{-1} \text{ cm}^{-2}] \]

What arrives at the front of the telescope, from a direction \( x \), with energy \( E \), at time \( t \)

Watch out for those units!

Often modeled with parameters \( \theta \)
\[
\lambda(x', E', t'; \theta) = \int \int \int dt \, dE \, dx \, f(x, E, t; \theta) \, A(E; x', t, f) \, P(x, x'; E, t, f) \, R(E, E'; x', t, x) \, \Delta(t, t')
\]

Effective area

\[
A(E; x', t, f) \, [\text{cm}^{-2}]
\]

Describes the efficiency with which incoming photons are detected

Mostly a function of energy, but also depends on where on the detector the photon falls

Can be affected by the brightness of source via Pileup, gain non-linearity, etc.
SDSS Filters

http://www.sdss.org/instruments/camera/#Filters
\[
\lambda(x', E', t'; \theta) = \int \int \int dt \, dE \, dx \, f(x, E, t; \theta) \, A(E; x', t, f) \, P(x, x'; E, t, f) \, R(E, E'; x', t, x) \, \Delta(t, t')
\]

Point Spread Function (PSF)

\[ P(x, x'; E, t, f) \]

Describes the probability that a photon from direction \( x \)
lands in detector pixel \( x' \)

- Energy dependent
- Distorted by pileup

aka Modulation Transfer Function (MTF) in Fourier Space
HUBBLE SPACE TELESCOPE
FAINT OBJECT CAMERA
COMPARATIVE VIEWS OF A STAR

BEFORE COSTAR

AFTER COSTAR

http://www.cv.nrao.edu/~pmurphy/images/astro/FOCpsfBW.png
Chandra Point Spread Function

Effect of pileup

Counts image (left) vs flux image (right). Pileup changes spectral shape, sometimes leads to loss of photons.
\[ \lambda(x', E', t'; \theta) = \int \int \int dt \, dE \, dx \, f(x, E, t; \theta) \, A(E; x', t, f) \, P(x, x'; E, t, f) \, R(E, E'; x', t, x) \, \Delta(t, t') \]

Spectral Response Matrix Function (RMF)

\[ R(E, E'; x', t, x) \]

Describes the probability that a photon of energy \( E \) is recorded in detector channel \( E' \)

Detector position dependent, in special cases, also dependent on incoming direction

Think as probability; rows of matrix sum to 1.
Chandra ACIS Fe$^{55}$ calibration
Line Spread Function: Chandra vs XMM

For grating spectra, LSF is determined by PSF.
\[ \lambda(x',E',t';\theta) = \int \int \int dt dE dx f(x,E,t;\theta) A(E; x',t,f) P(x,x'; E,t,f) R(E,E'; x',t,x) \Delta(t,t') \]

Timing corrections

\[ \Delta(t,t') \]

Types of corrections:

frame time / integration time
dead time
Barycentric
\[ \lambda(x', E', t'; \theta) = \int \int \int dt \, dE \, dx \, f(x, E, t; \theta) \, A(E; x', t, f) \, P(x, x'; E, t, f) \, R(E, E'; x', t, x) \, \Delta(t, t') \]

Statistics Notation: \( \lambda \)

Expected intensity

\[ \lambda(x', E', t'; \theta) \]

Not a measurement

In the absence of perfect knowledge, construct a model function and ask how close it got to the observed data