CHASC AstroStatistics Center

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hea-www.harvard.edu › astrostat

CHASC: AstroStatistics

International **CHASC Astro-Statistics** Collaboration. This page lists resources of specific interest to astronomers. For detailed descriptions and reports of C-BAS/ ...

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AstroStat Talks 2020-2021
Abstract: We investigate the use of data-driven likelihoods to ...

Mailing-List
... (or) astrostat-announce@head .cfa.harvard.edu; This is a ...

Advances in Bayesian ...
Last Updated: 20170727. HEAD 16: Special Session.

Tutorials on AstroStatistics and...
Eric Feigelson (Penn State University) gave a series of ...

Topics in AstroStatistics
10:00 am: Yang Chen (University of Michigan) · The Bayesian ...

The AstroStat Slog
About. BIRTH. This is designed as a means to convey Statistics ...

More results from harvard.edu »

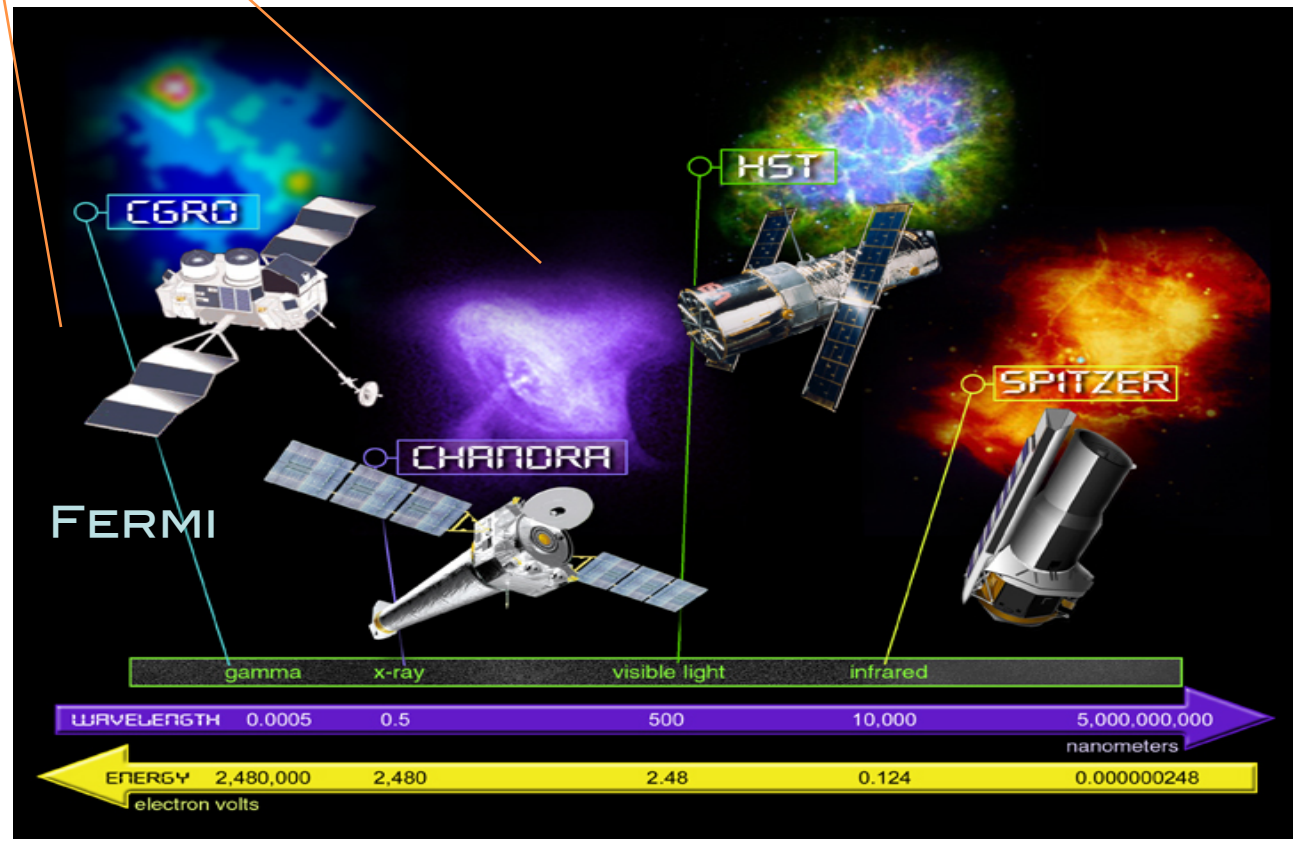
http://hea-www.harvard.edu/AstroStat/

CHASC was founded in 1997

High-Energy Astrophysics

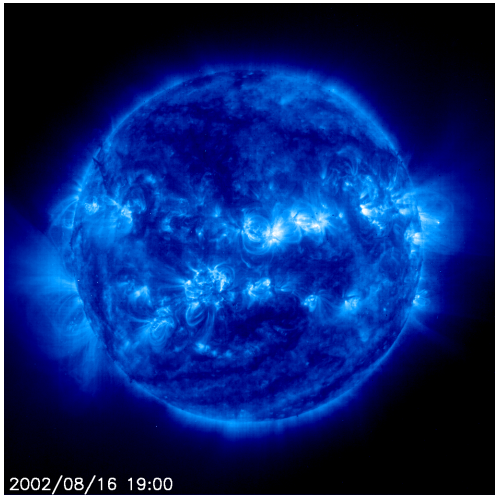
X-rays and Gamma-rays $< 10^{-6}$ cm or $> 2 \times 10^{16}$ Hz

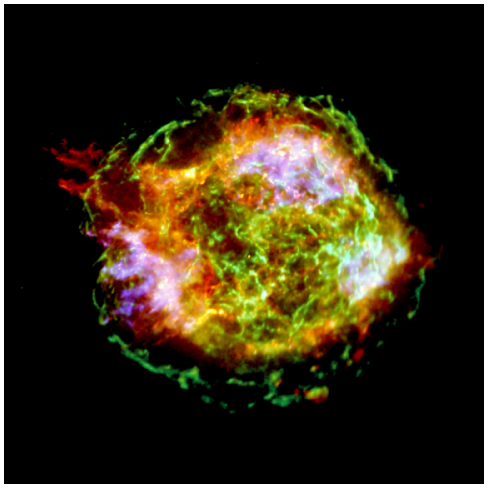
Not visible from the ground - Space-based observations

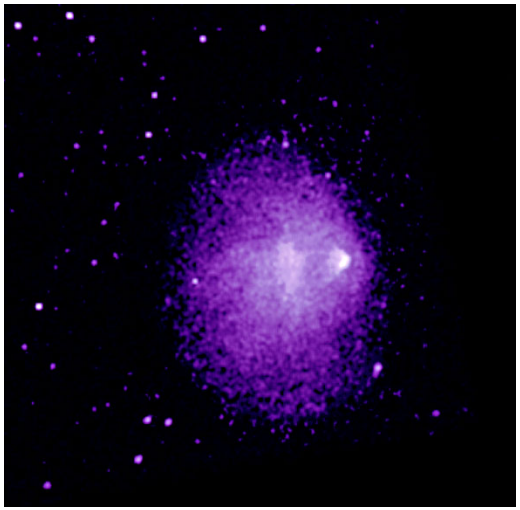


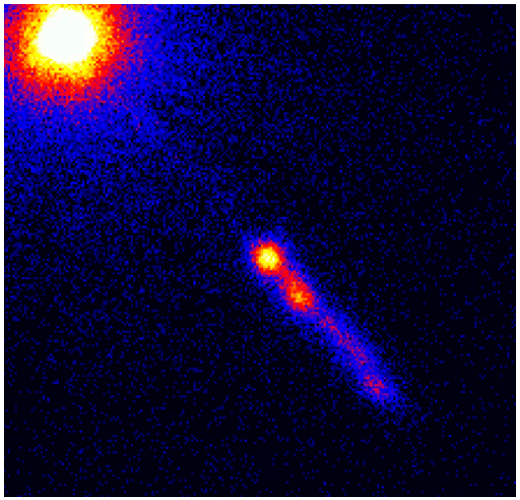
Sources of High-Energy Radiation

- Stellar Coronae
- Supernova remnants
- Galactic outflows
- Clusters of galaxies
- Compact objects:
  neutron stars,
  accreting black holes,
  supermassive black holes
- Relativistic jets
- GRBs
- etc…



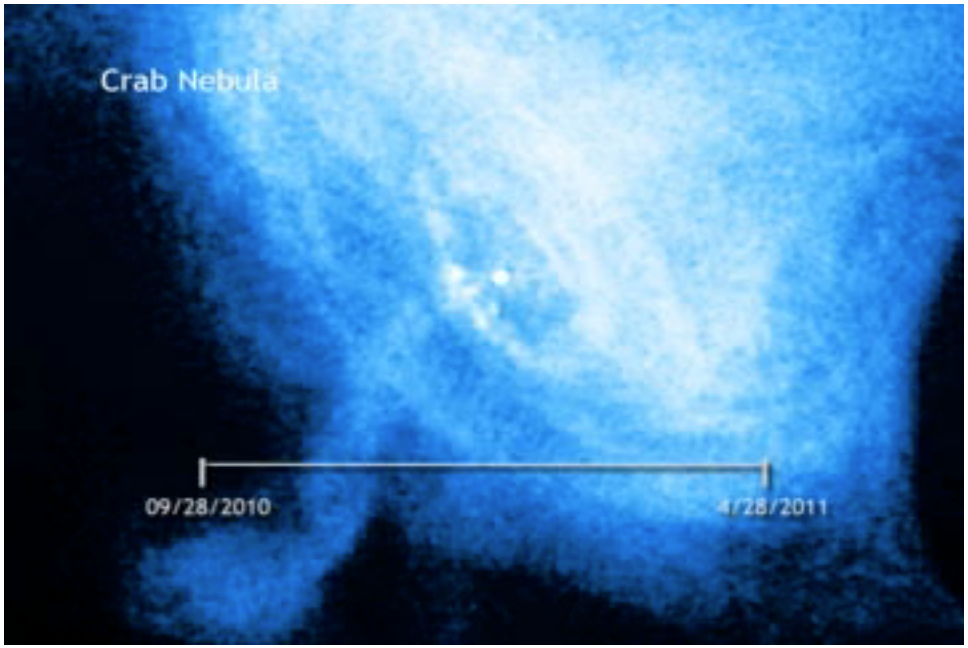






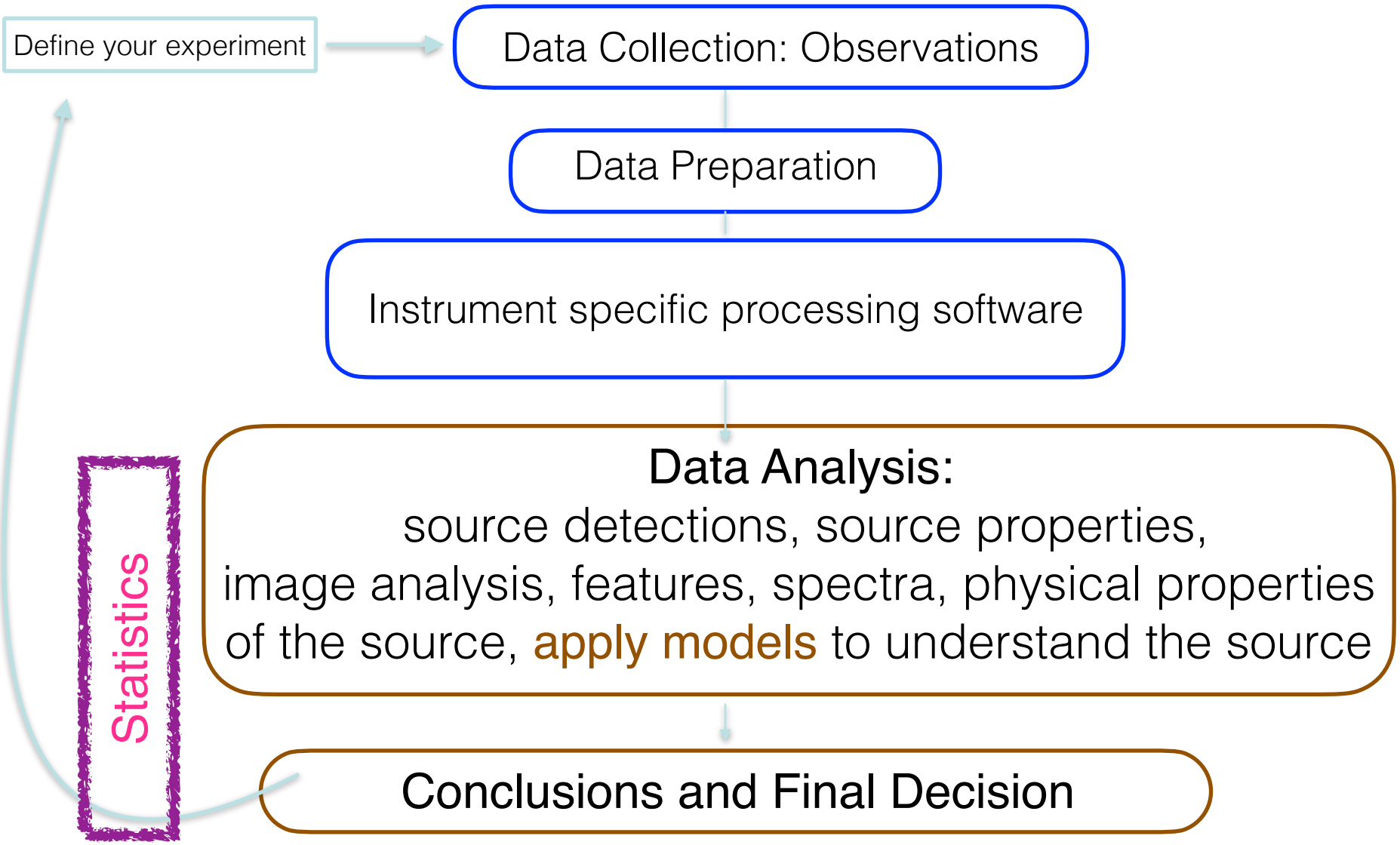
Data in High-Energy Astrophysics

- X-ray and γ-ray data count photons => Poisson in nature
- Complex physics and data collection
- Data may exhibit Spectral, Temporal and Spatial variations



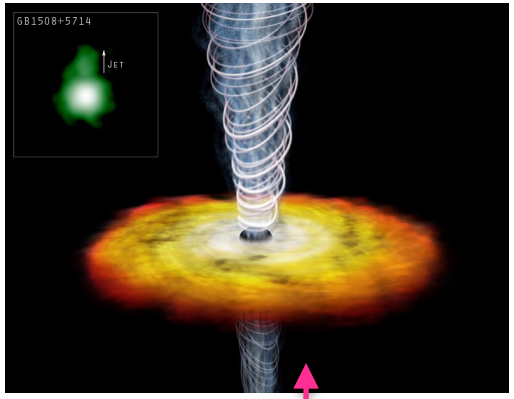
Crab Nebula - variations during 6 month of snap-shot observations with Chandra X-ray Observatory

Scientific Experiment



Observations and Data Collection

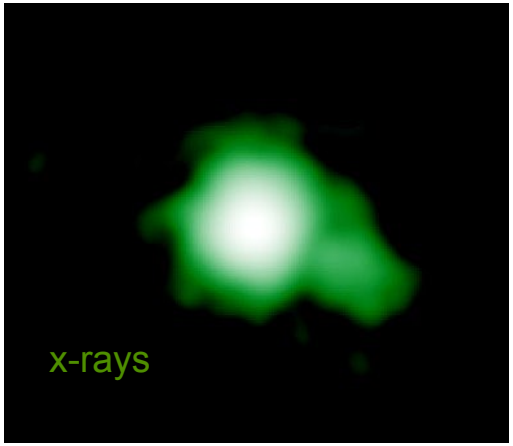
Astrophysical process



Random number of photons reach the detector

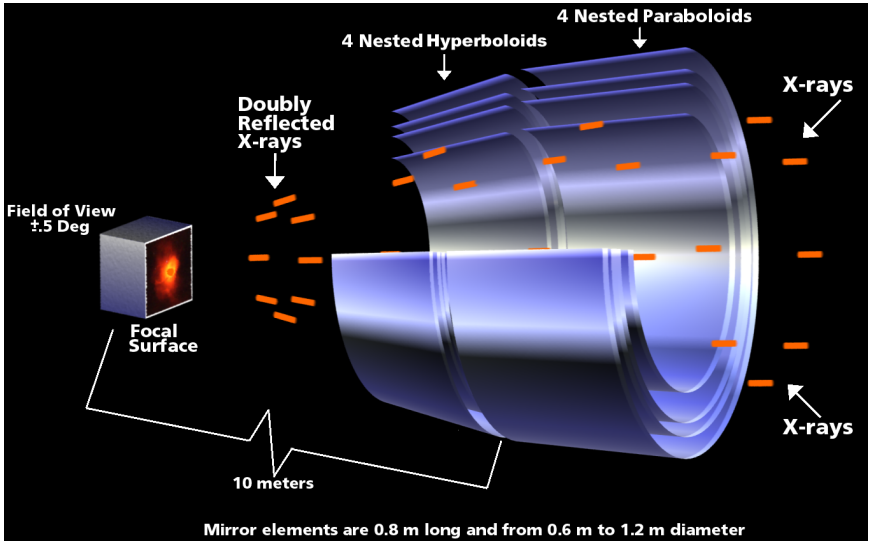
Detector collects photons, adds noise

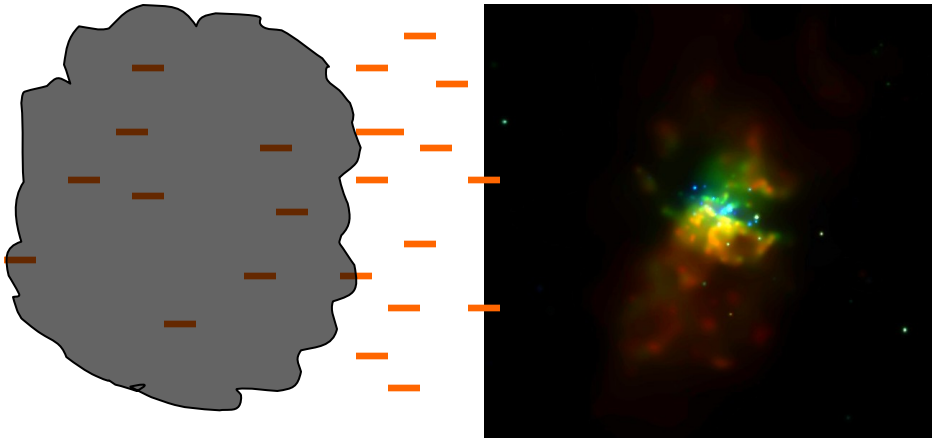
draw conclusion about the astrophysical source



Data Collection in Space

Chandra X-ray Observatory





Telescope + Detectors

Measurement Process
Inefficient data collection Process
Instrument characteristics
Instrument Calibration

Interstellar Medium

Loss of signal
but also imprints
information

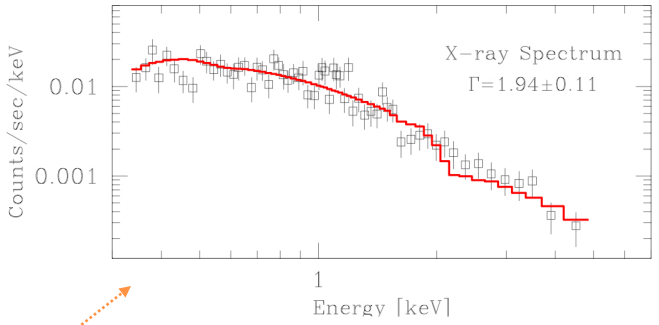
Astronomical Object

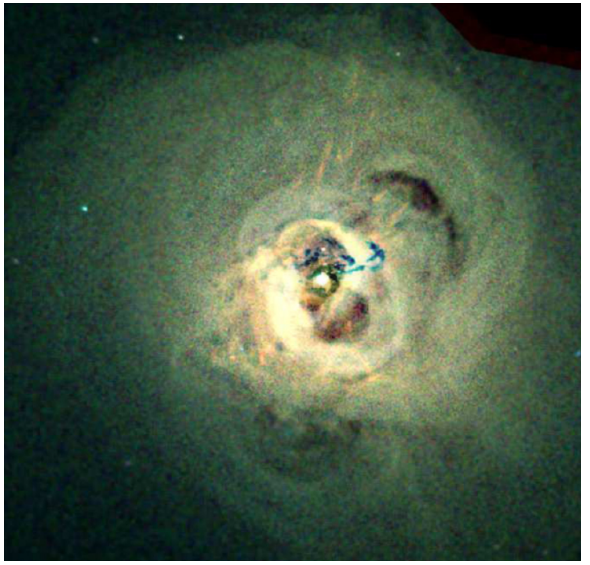
Physics

Data Collection

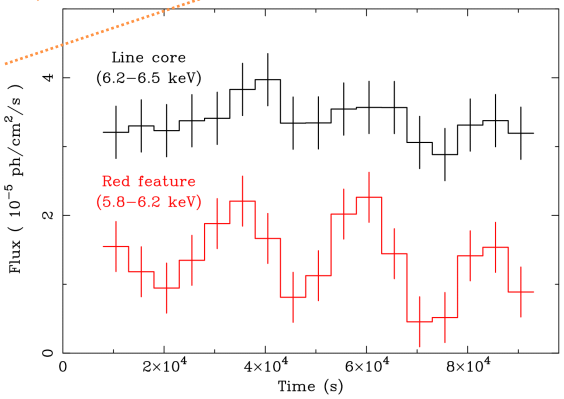
- Data are recorded for each arriving photon:
  - the (2-dimensional) location - sky coordinates
  - the photon energy
  - the arrival time
- All variables are discrete
  - High resolution -> finer discretization,
  - e.g., 4096 x 4096 spatial or up to 16384 spectral bins
- Table with photon counts for:
  - Spectral analysis - 1D
  - Spatial analysis - 2D
  - Timing analysis - 1D

Energy Spectra 1D



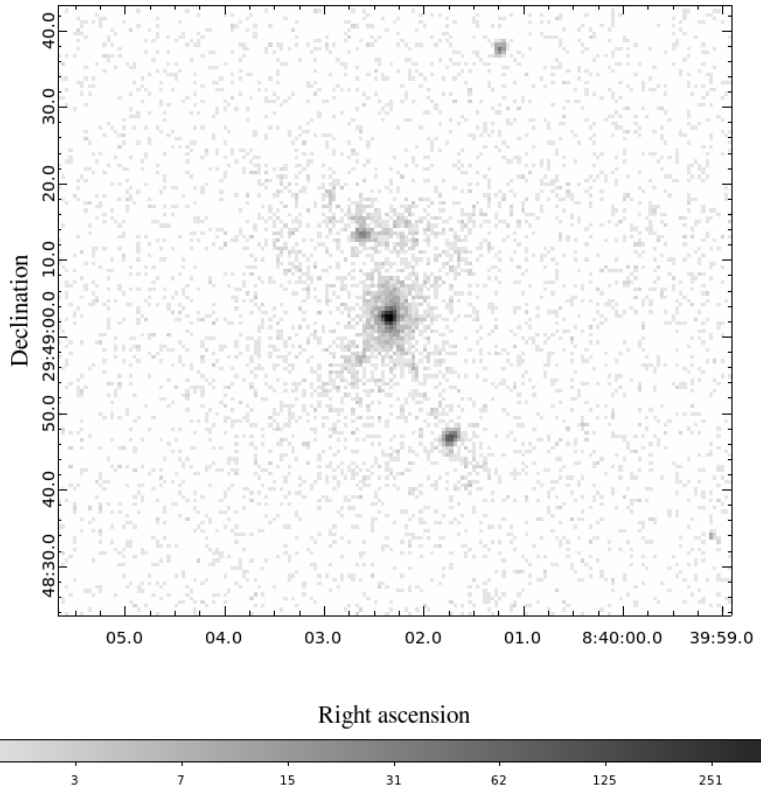


Chandra X-ray Image

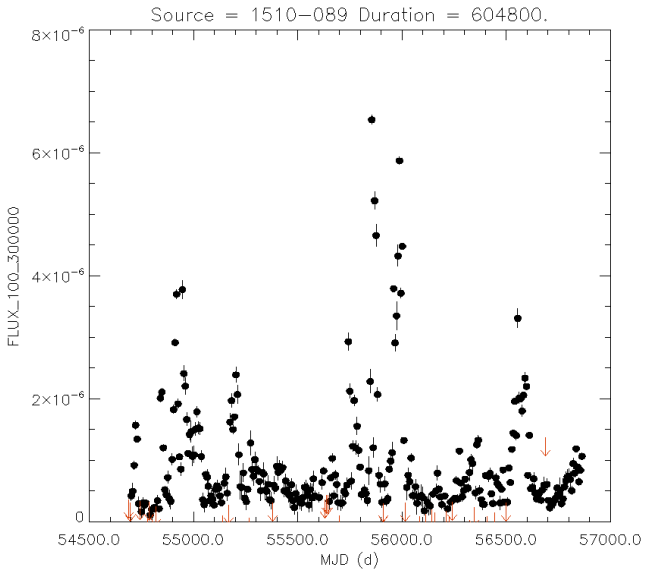


Challenges

- Sparse, locally saturating, Poisson data
- Instrumental effects
- Source Detection in Deep Images
- Irregular extended structures
- Source boundaries
- Complex physical models
- Non-periodic, stochastic variability



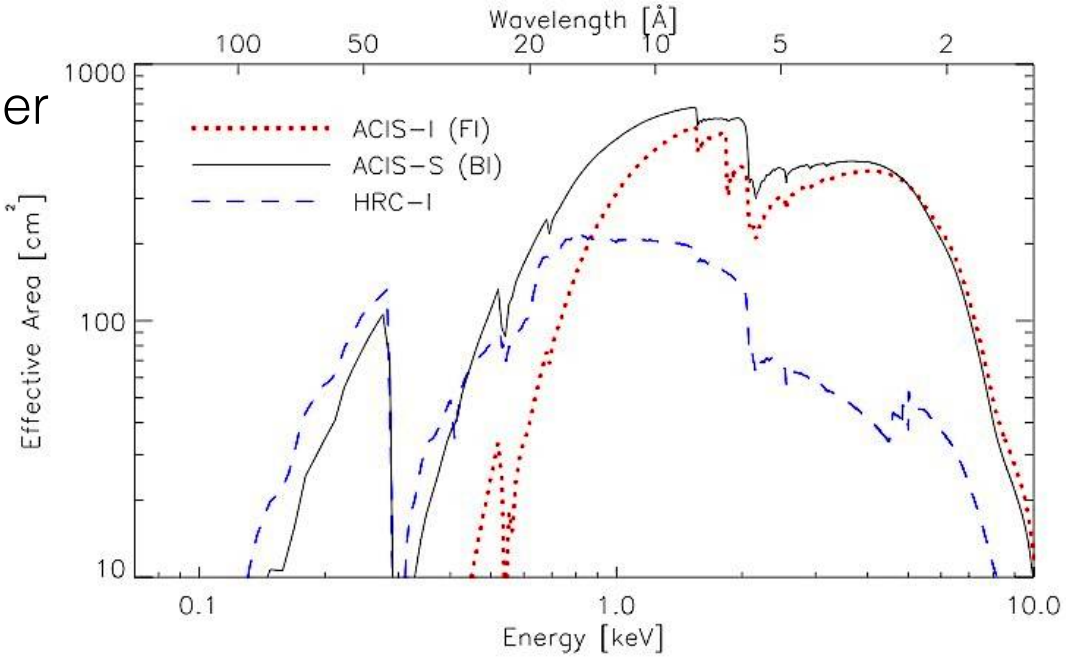
Chandra X-ray Observatory



Fermi LAT

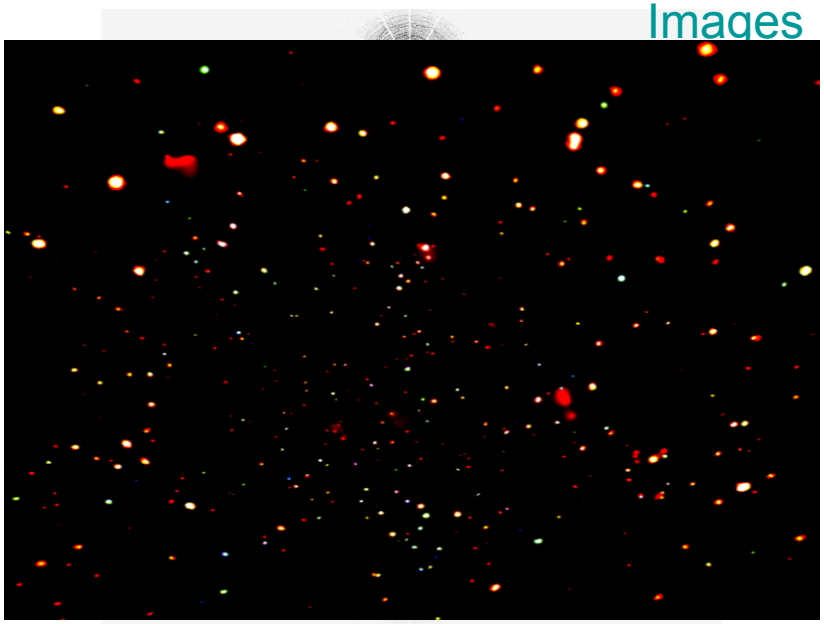
Instrumental Effects: Recording inefficiency

- Image:
  - exposure map
    "sensitivity to photons per area"
- Spectrum:
  - effective area (ARF)
    "sensitivity to photons per energy"



Instrumental Effects: Blurring

PSF Simulated Images

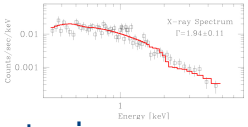


- Image

  (a number of counts in a pixel)

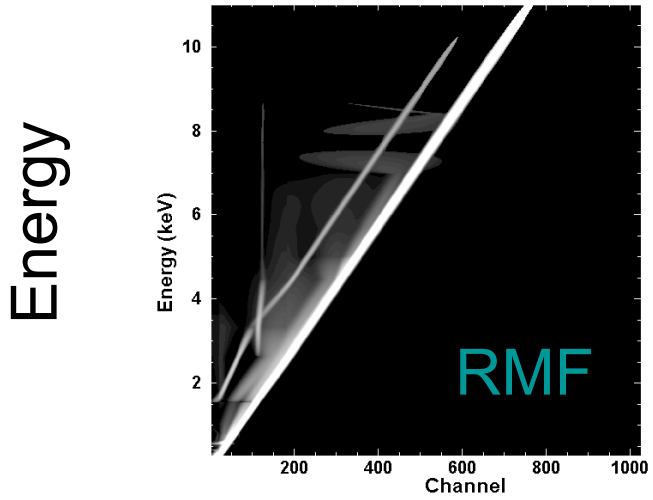
  - observed point source size depends on the source location on the detector
  - "blurring" is described by a point spread function (PSF)

- X-ray Spectrum



  (a number of counts in energy bin)

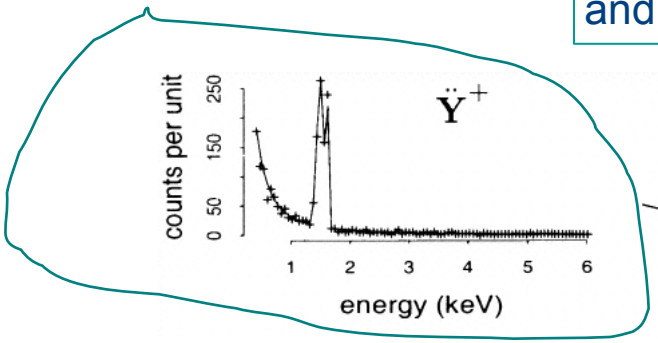
  - photon energy is "blurred"
  - probability of detecting photon at given energy in given detector channel is described by a redistribution matrix (RMF)



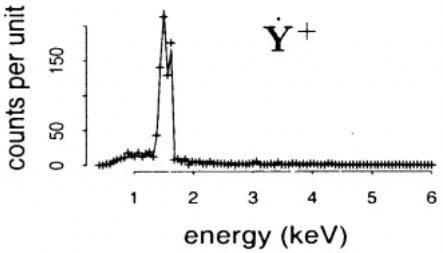
Highly Structured Statistical Models

Model directly the source and data collection, and include statistical procedure to fit the resulting highly structured models and address the substantial scientific questions

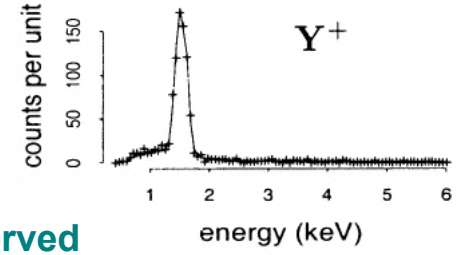
Emitted Spectrum



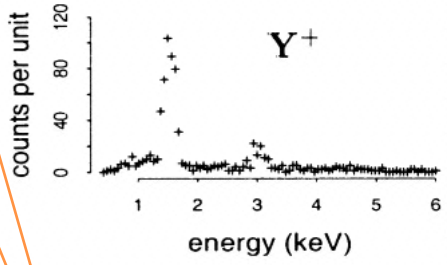
absorbtion and submaximal effective area



instrument response

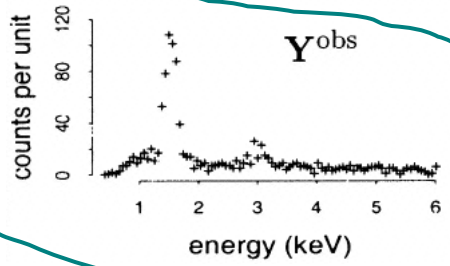


pile-up



Observed

background



Loss of information

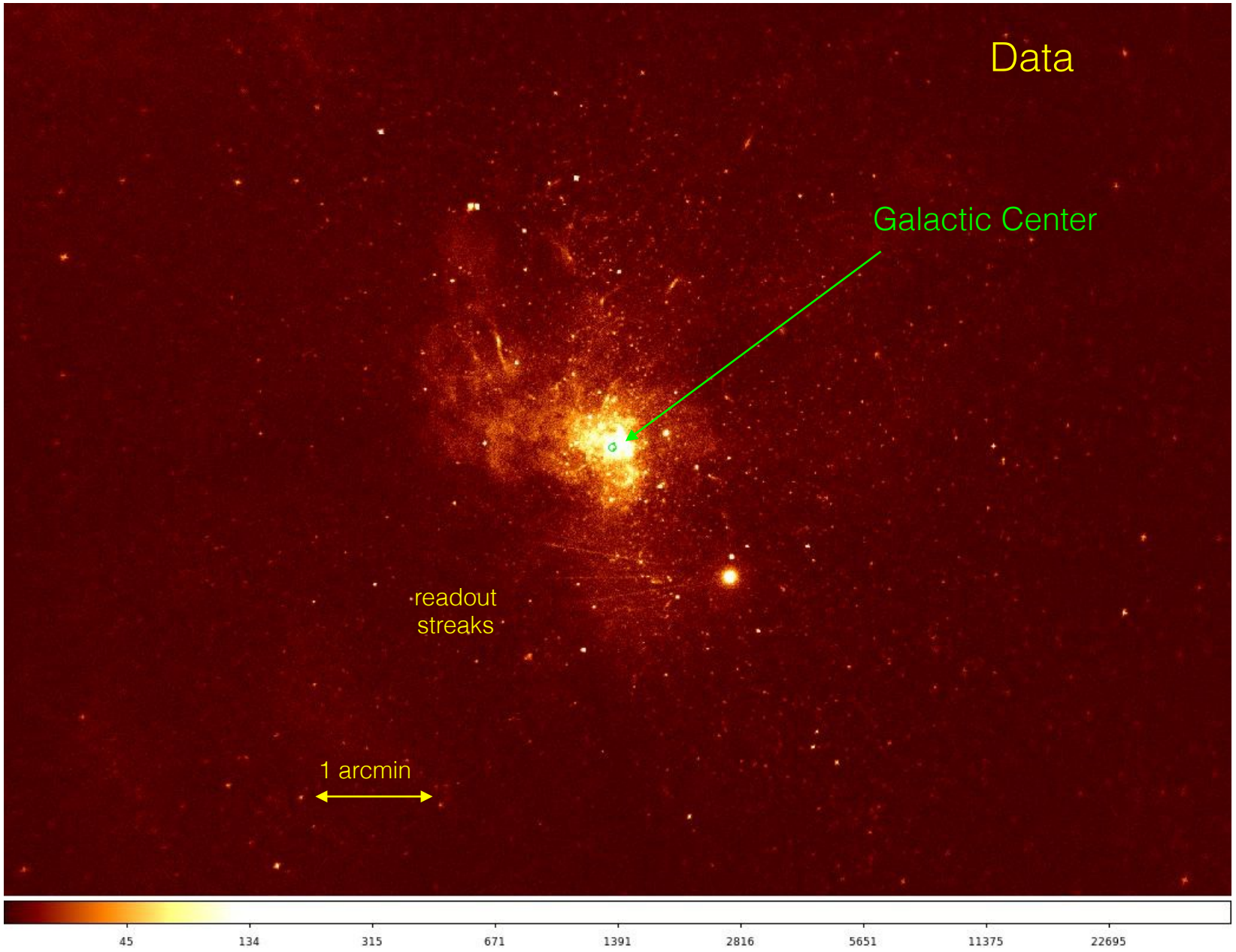
van Dyk et al. 2001

A Few Projects

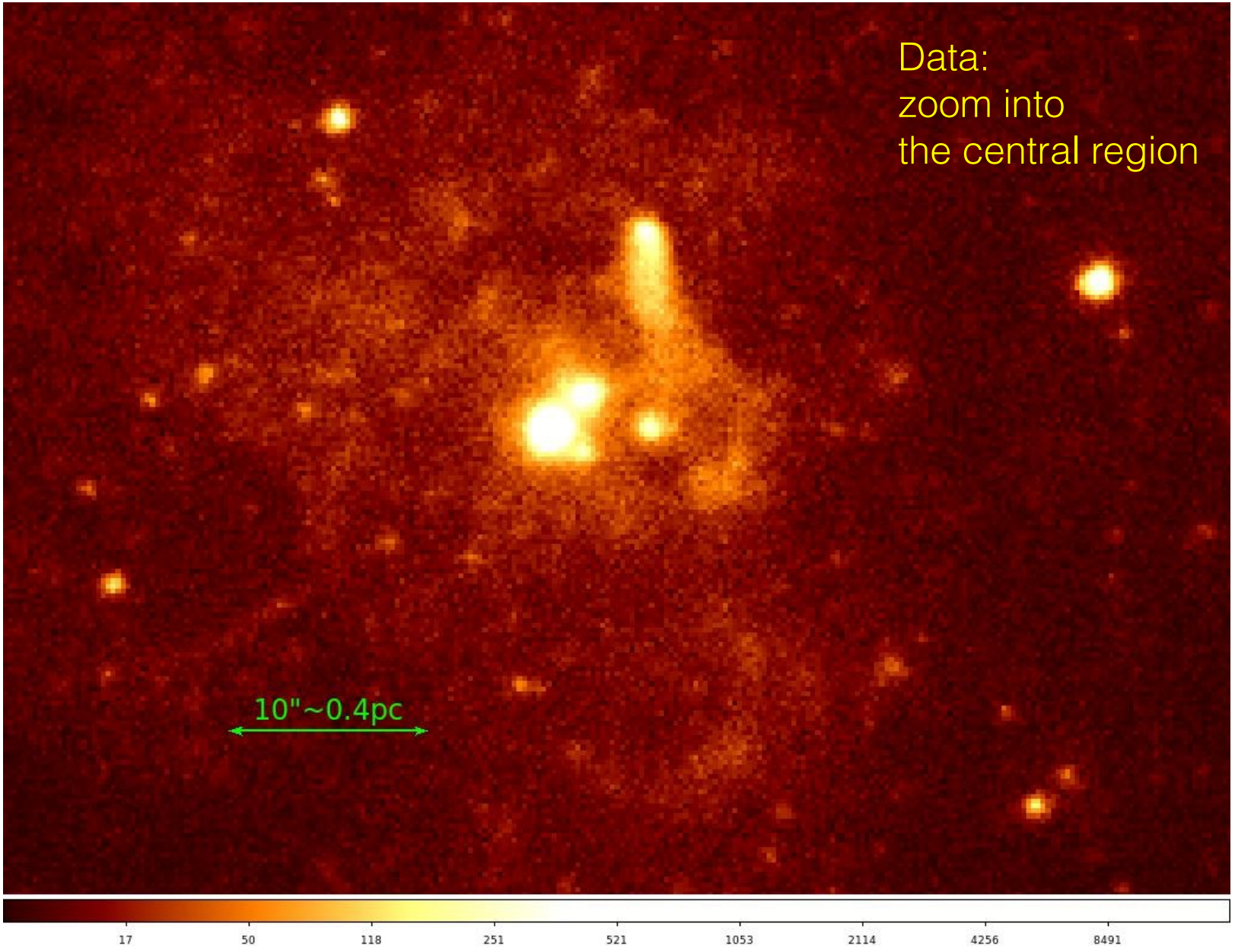
- Shapes and significance of structures in X-ray images


smoothed
Galactic Center

Merged 72 ACIS observations 2000-2014 (~2.2 Msec exposure)



Merged 72 ACIS observations 2000-2014



A Few Projects

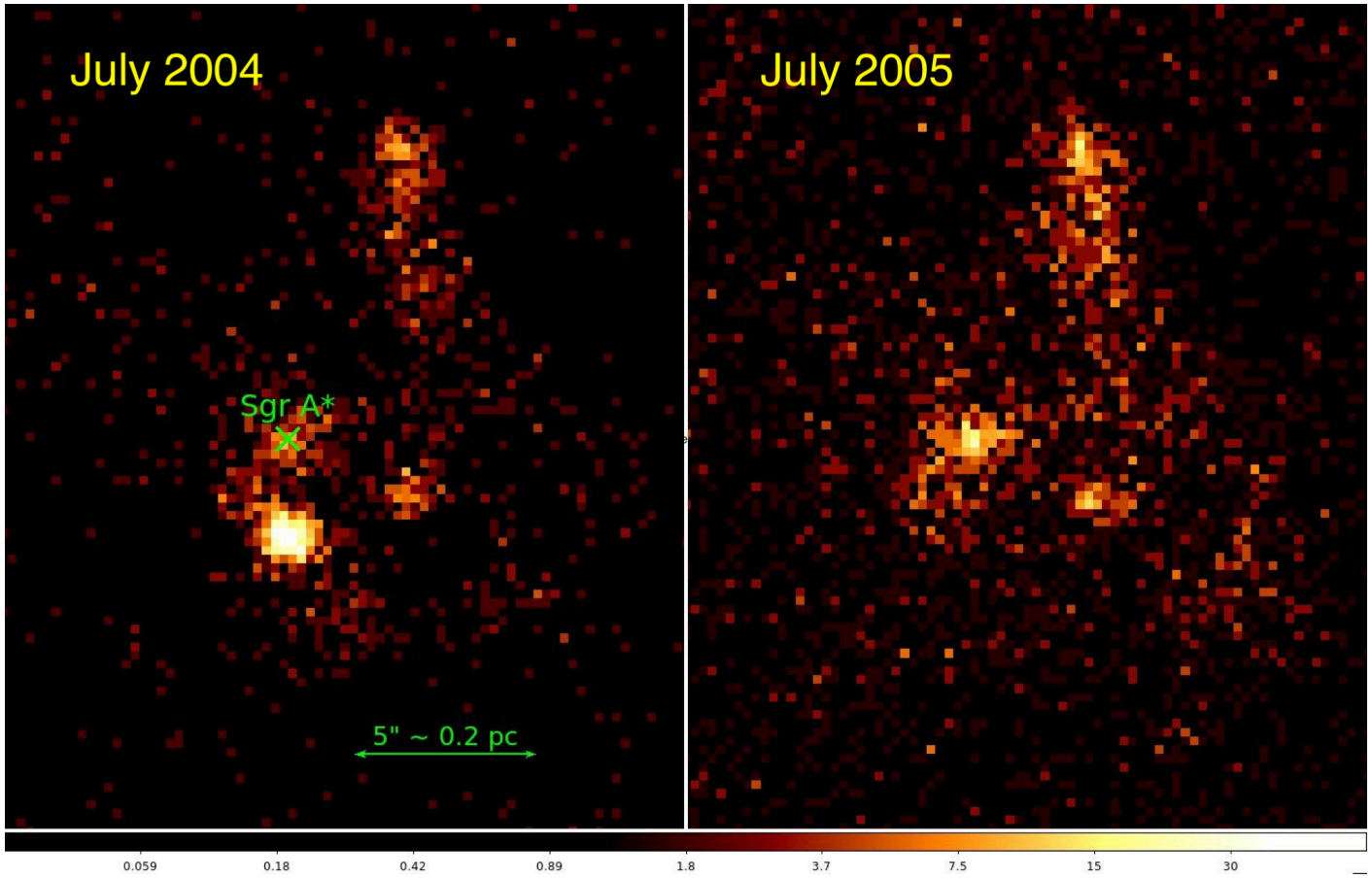
- Shapes and significance of structures in X-ray images
- Spectral information in the images - hardness ratio, temperature maps, boundaries of spectral regions
- Crowded fields with multiple sources in a PSF region
- Accounting for systematic uncertainties in image analysis

Crowded Fields

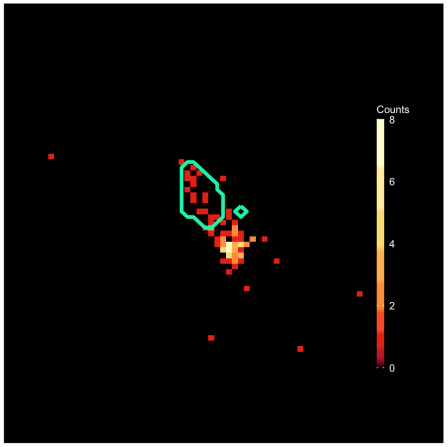
resolution, overlapping psf, source variability

Chandra images of the Galactic Center

Data - zoom

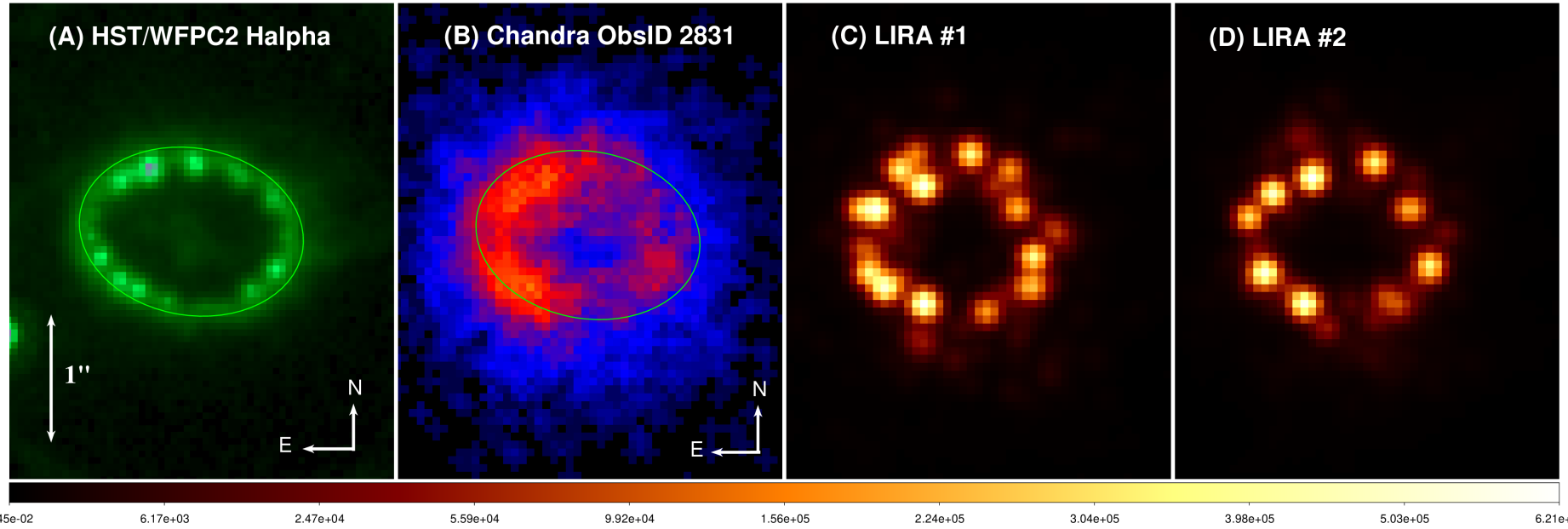


region boundaries

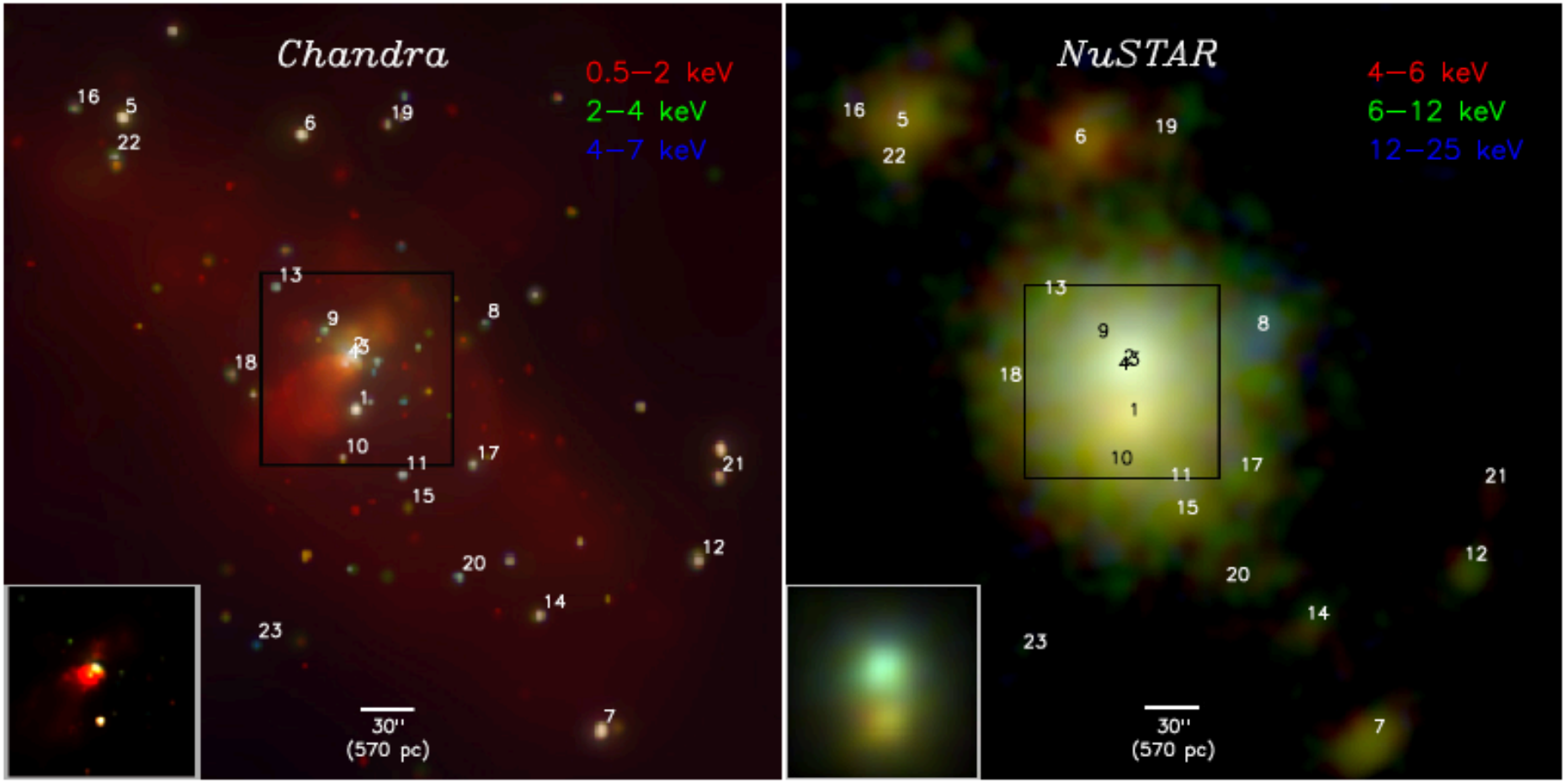


Katy McKeough

PSF uncertainties



Images with Different Resolution



A Few Projects

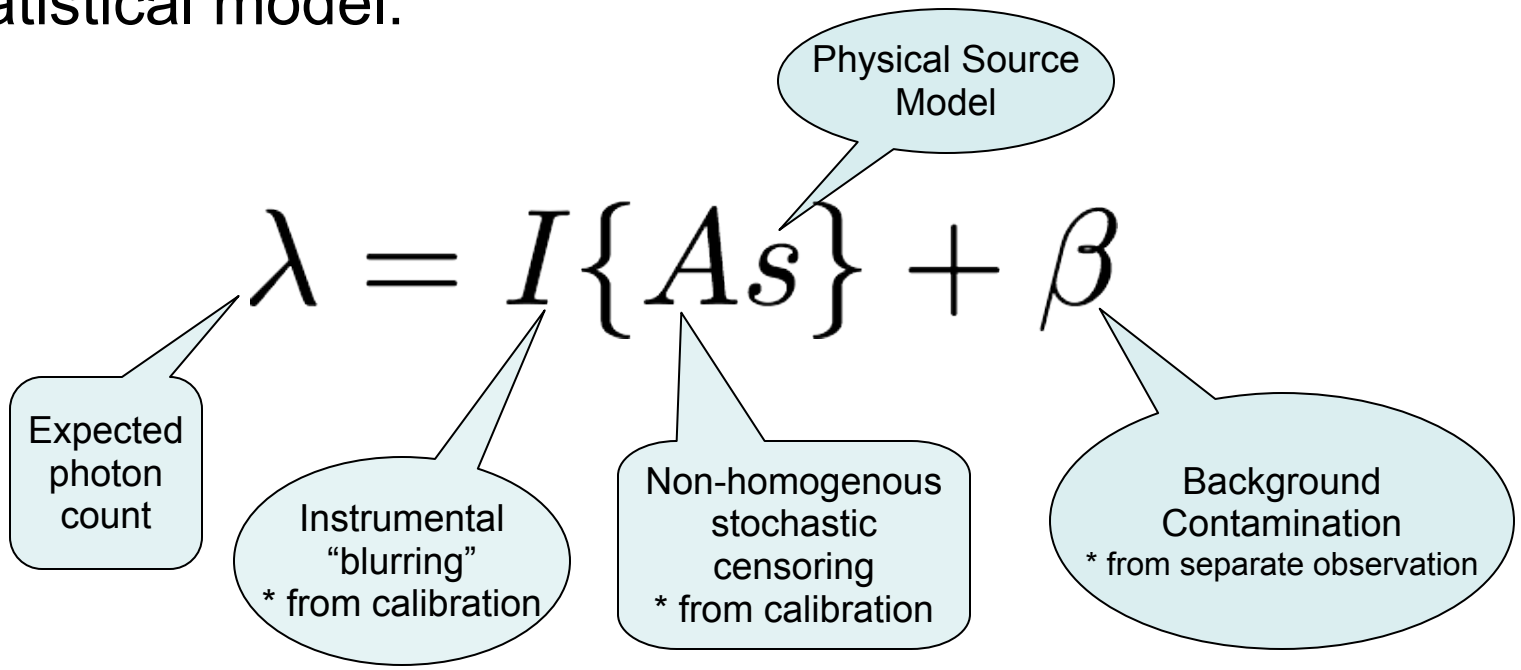
- Shapes and significance of structures in X-ray images
- Spectral information in the images - hardness ratio, temperature maps, boundaries of spectral regions
- Crowded fields with multiple sources in a PSF region
- Handling images with different resolution - Chandra/XMM/NuStar images.
- Accounting for systematic uncertainties in image analysis
- Identifying break points in multi-dimensional data
- Efficient computations - improvements on the current algorithms

Statistical Paradigm

- Model Building:
  - Model source spectra, image, and/or time series
  - Model the data collection process
    - Background contamination
    - Instrumental effects (effective area, response, psf)
  - Results in a highly structured hierarchical model
- Model-Based Statistical Inference
  - Bayesian posterior probability distribution
  - Maximum likelihood estimation
- Sophisticated Statistical Computation Methods are Required
  - Goals: computational stability and astronomer- friendly implementation
  - Emphasize natural link with models: The Method of Data Augmentation

Bayesian Inference

- Complex data collection needs to be included in the statistical model:



Observed counts are modeled as independent Poisson variables with λ mean