Sherpa

Aneta Siemiginowska

Harvard-Smithsonian Center for Astrophysics

Chandra X-ray Center

CHASC Astrostatistics

Presented by: G. Fabbiano & O. Laurino

Scientific Experiment

Observations

Data Reduction and Processing

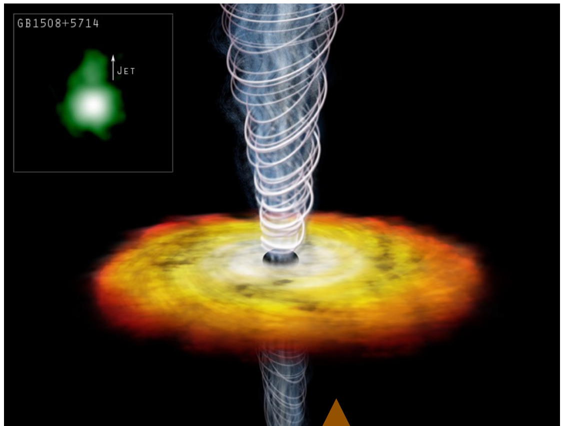
Scientific Analysis

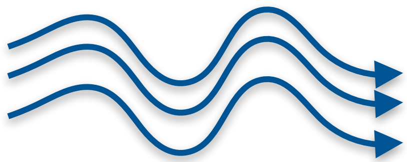
Results

Conclusion and Final Decision

Observations and Data Collection

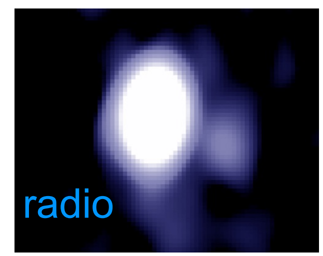
Astrophysical process

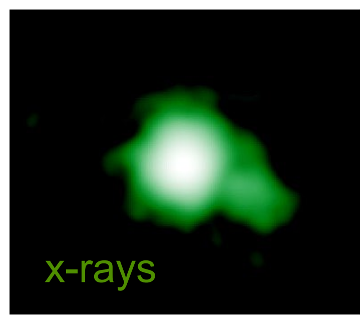


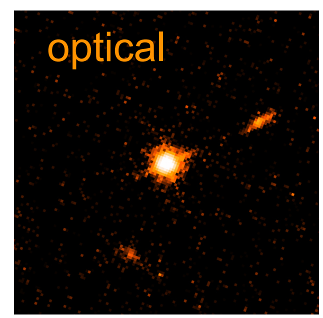


Random number of photons reach the detector

Detector collects photons, adds noise

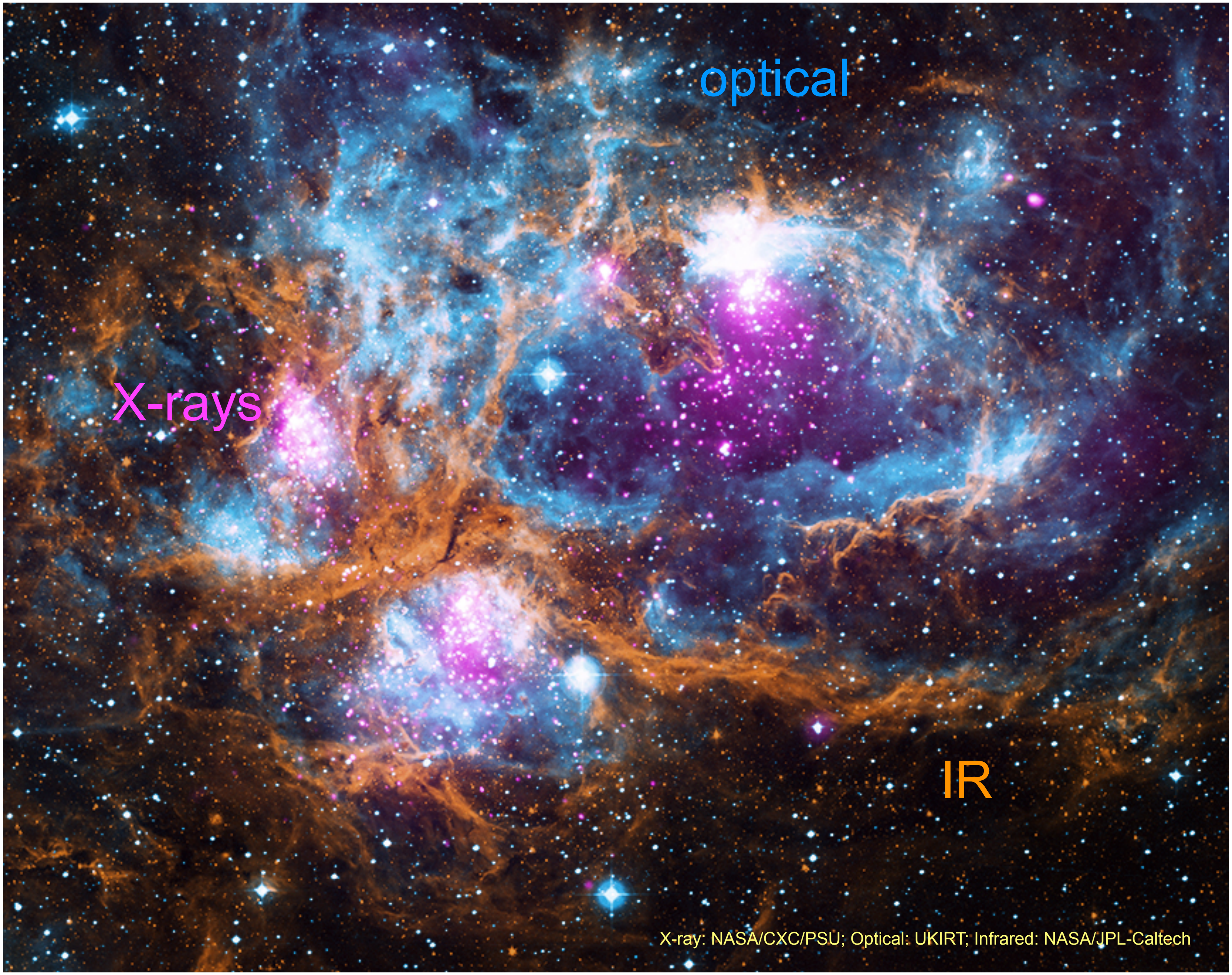






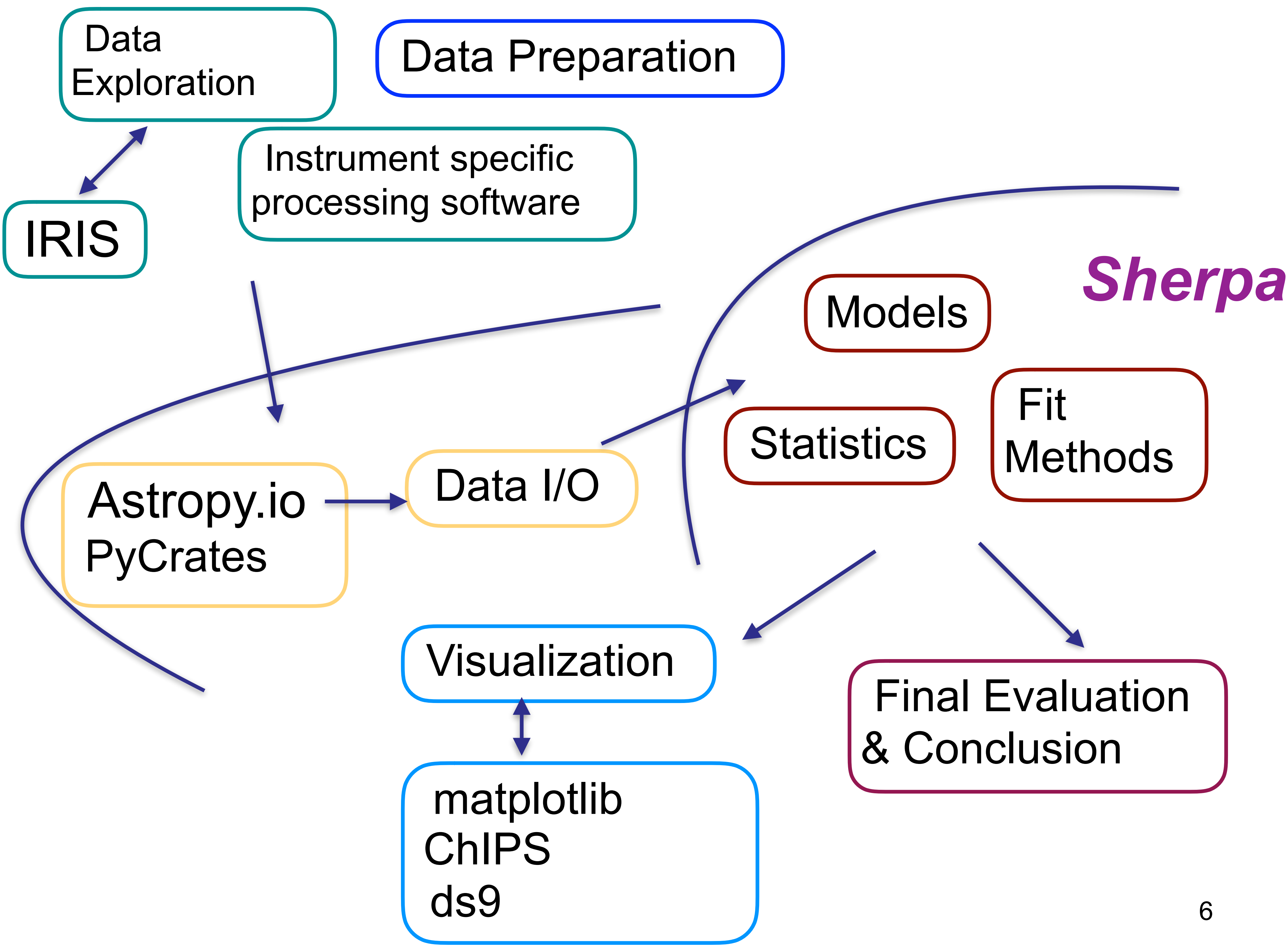
?

draw conclusion about the astrophysical source



NGC 6357
Star-forming
Region

Townsley, L. et al. (2014)

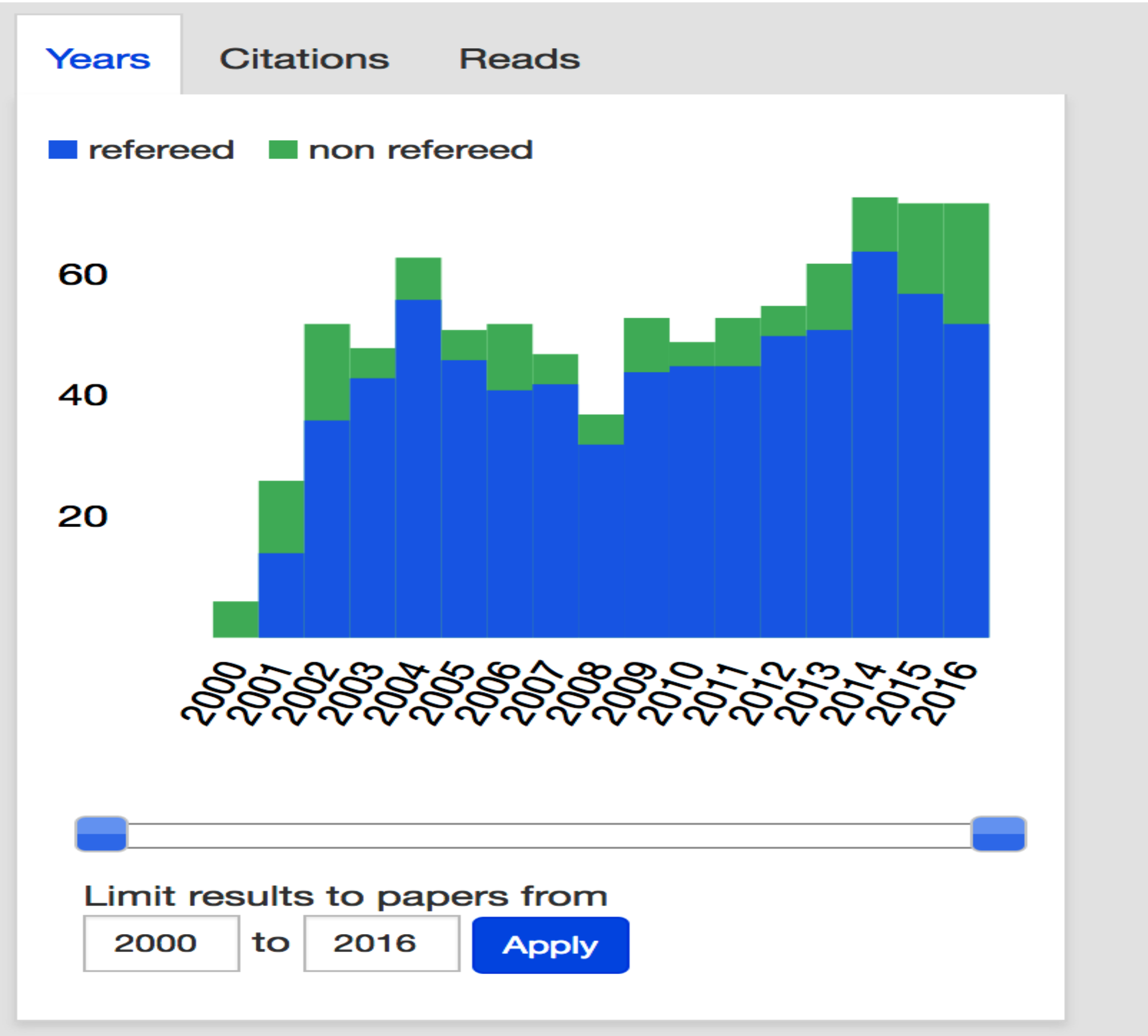

Data Exploration
Data Preparation
Instrument specific processing software
IRIS
Sherpa
Models
Statistics
Fit Methods
Astropy.io
PyCrates
Data I/O
Visualization
Final Evaluation & Conclusion
matplotlib
ChIPS
ds9

Sherpa

- Modeling 1D/2D (N-D) data: arrays, spectra, images.
- Powerful language for building complex expressions.
- Provides a variety of statistics and optimization methods (including Bayesian analysis) .
- Support for wcs, responses, psf, convolution.
- Extensible to include user models, statistics and optimization methods.
- Included in several Software packages.
- Modeling and fitting application for Python.
- User Interface and high level functions written in Python.
- Source code on GitHub https://github.com/sherpa/sherpa
- Open development with continuous integration via Travis.

Sherpa in Astronomy Research

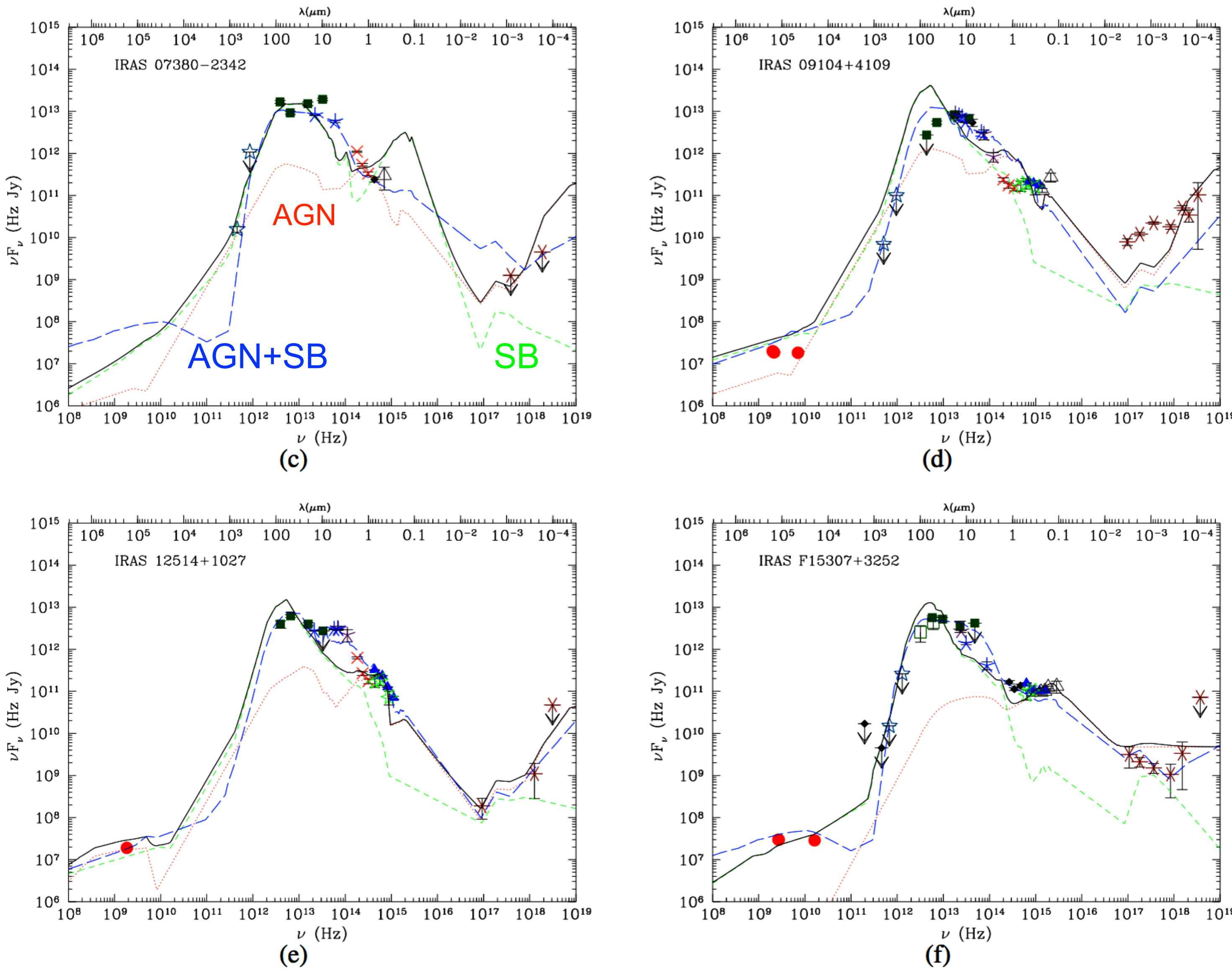
ADS search results



871 publications
cited the use of Sherpa

Mature Package:
15 years of development
8 years of Python code

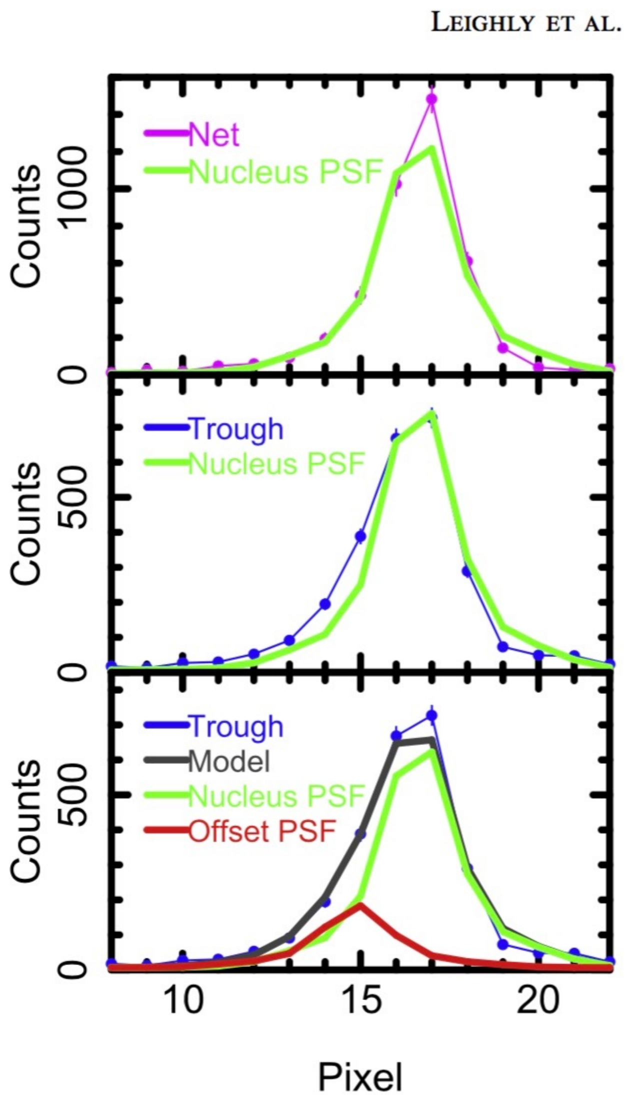
Spectral (SED) Fitting with Composite Templates

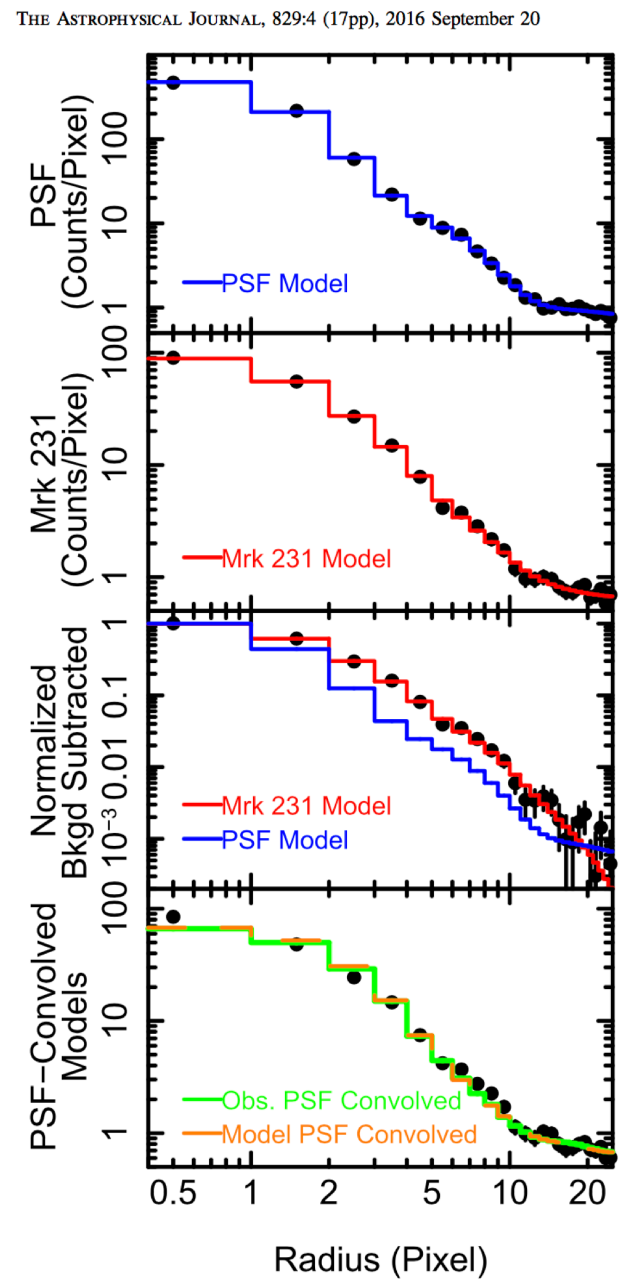


Ruiz et al. (2010)

Fig. 6. Rest-frame SED of class B HLIRG and their best-fit models. Symbols as in Fig. 5. The long-dashed lines (blue in the colour version) are the best fits obtained using composite templates (see Sects. 4.1 and 5.2).

Fitting Spatial Profiles of the HST observations of Mrk 231





Leighly et al. (2016)

Composite Models in BXA Bayesian X-ray Analysis

Buchner et al.: Absorption and reflection model comparison of AGN in the CDFS

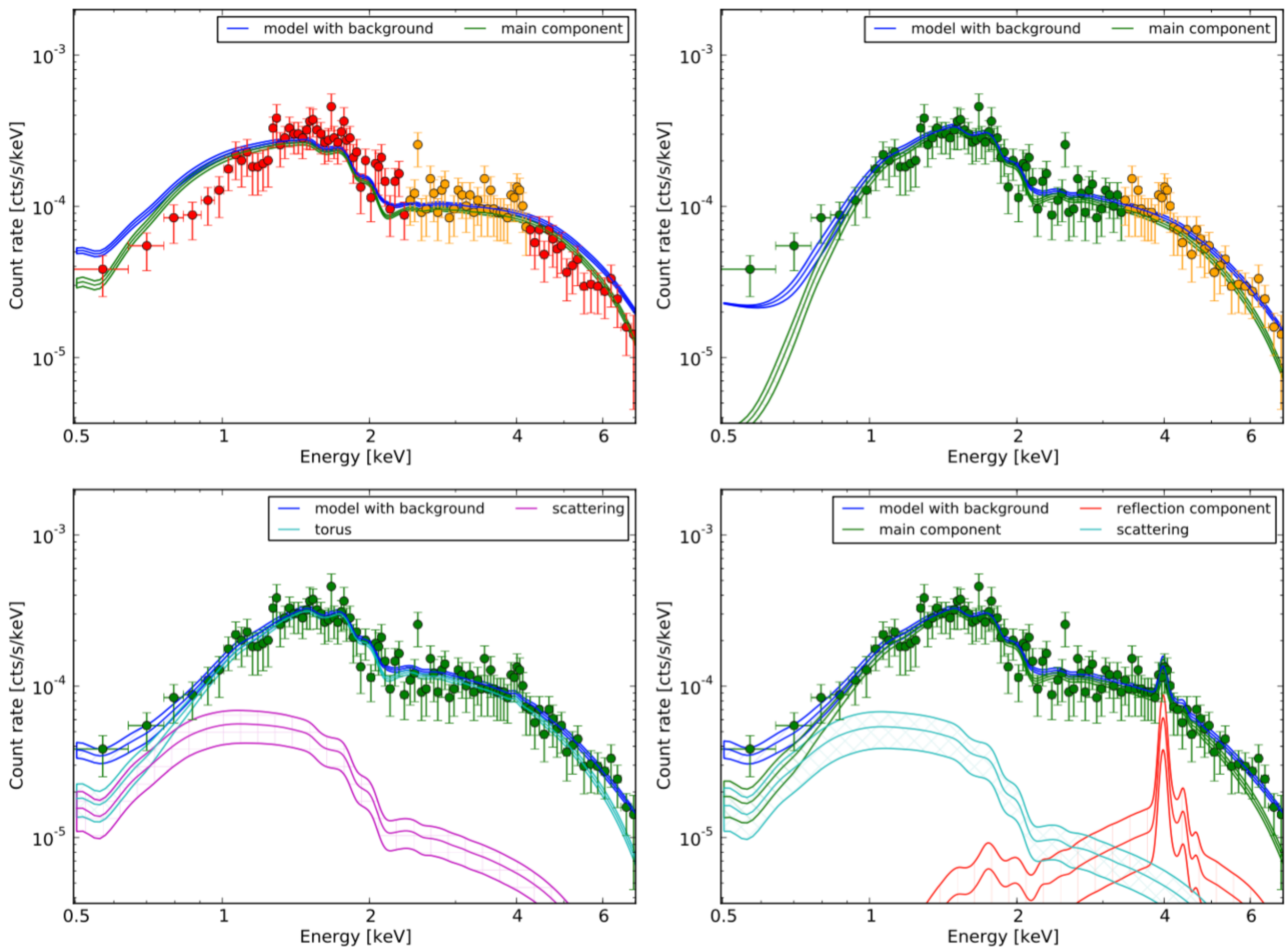


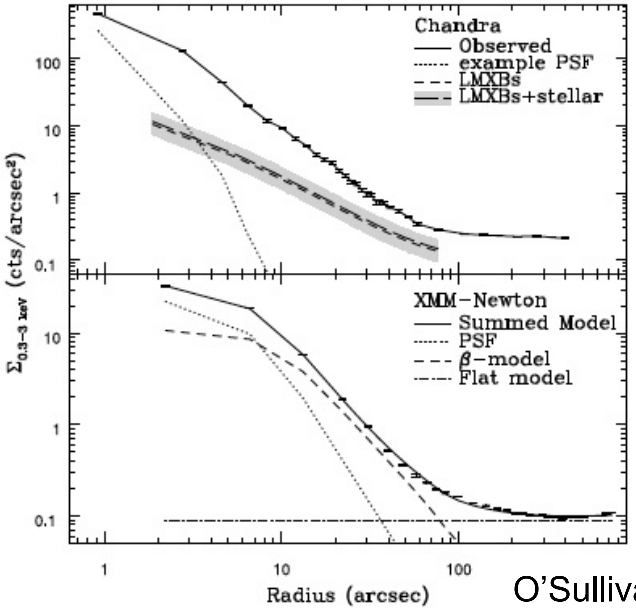
Figure 5: Observed (convolved) spectrum of object 179, binned for plotting to 10 counts per bin. Shown are analyses using various models and their individual components: **powerlaw** (upper left), **wabs** (upper right), **torus+scattering** (lower left) and **wabs+pexmon+scattering** (lower right). The posterior of the parameters are used to compute the median and 10%-quantiles of each model component.

Buchner et al. 2014

Chandra Deep Field South
X-ray Spectrum of an object fit
with different composite models

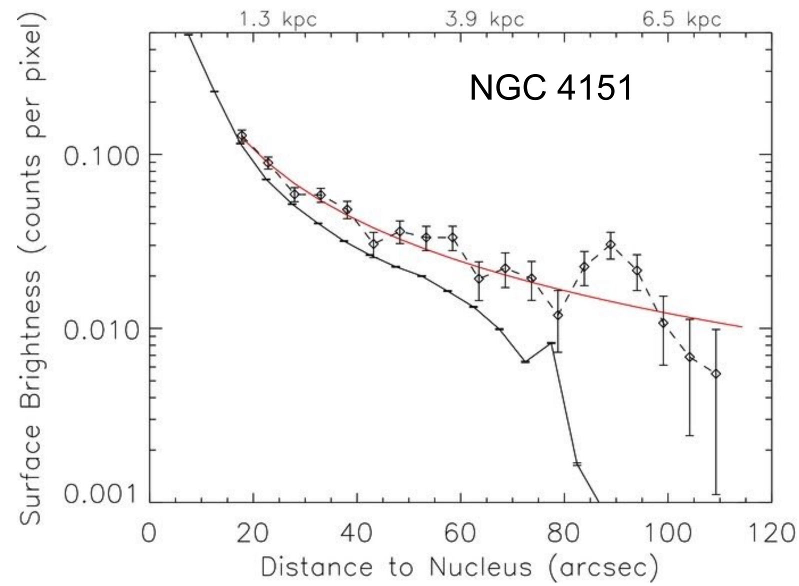
Chandra and XMM

Surface Brightness Profiles
(with & without PSF)



O'Sullivan et al. (2011)

Chandra



Wang et al. (2010)

HST Images

Radio loudness and surface brightness profile 2167

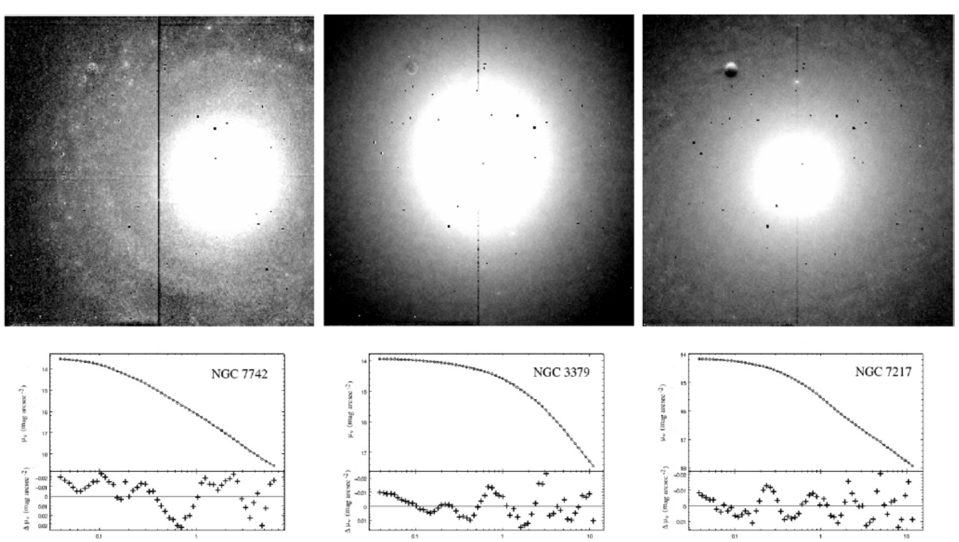


Figure 1. Galaxy images (top row) and radial brightness profiles (bottom row) for a confident Sérsic fit (NGC 7742; left), Core fit (NGC 3379; centre) and Double-Sérsic fit (NGC 7217; right).

Richings, Utley & Kording (2011)

Spatial Fitting of the TeV emission in H.E.S.S. observations

A&A 541, A5 (2012)

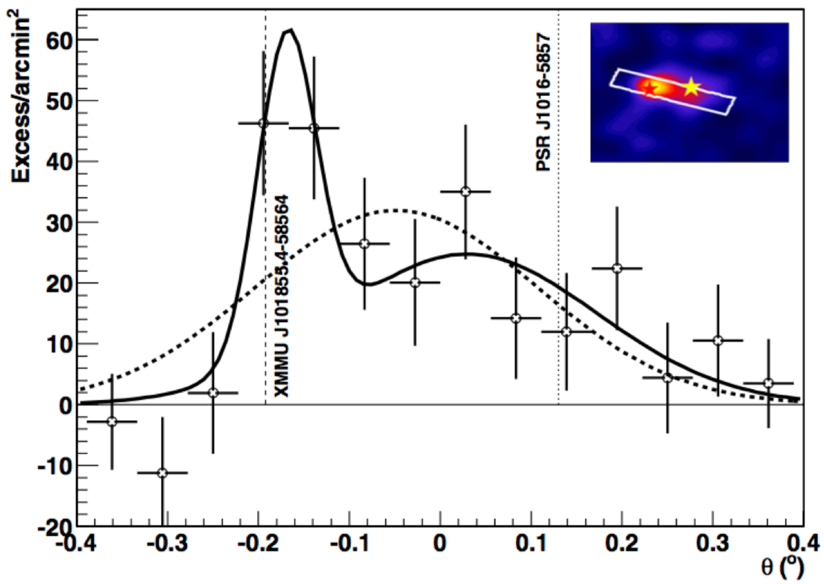


Fig. 3. Profile of the VHE emission along the line between the peak of the point-like emission and the peak of the diffuse emission, as illustrated in the inset. Fits using a single and a double Gaussian function are shown in dashed and solid lines respectively. The positions of XMMU J101855.4–58564 and PSR J1016–5857 are marked with dashed and dotted vertical lines and red and yellow stars in the inset, in which the significance image obtained using an oversampling radius of 0.1° is shown.

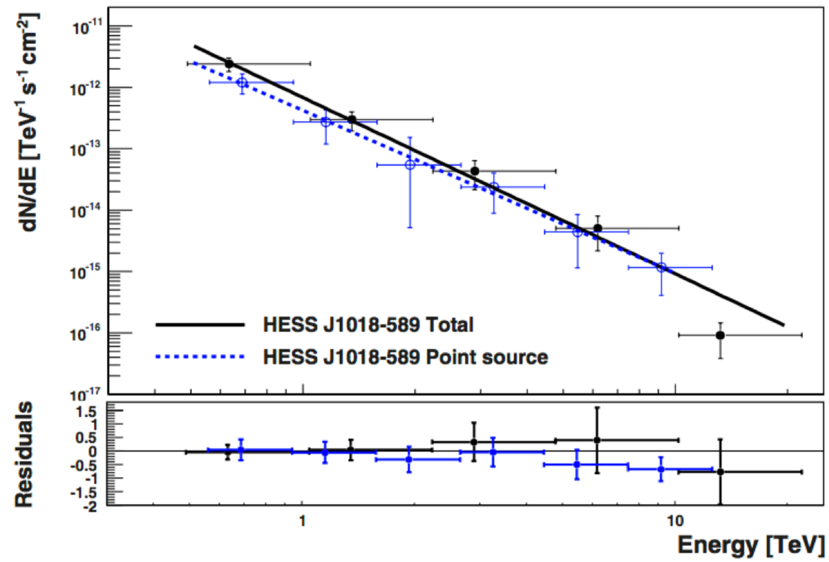
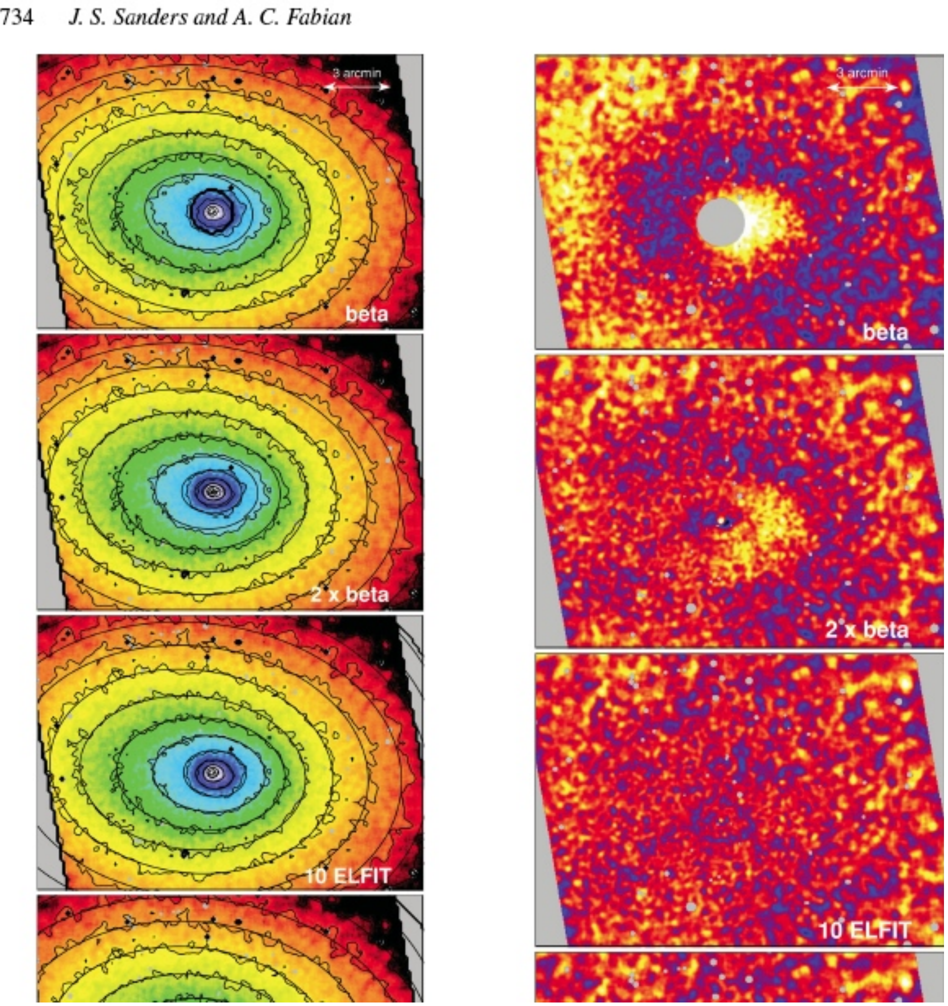


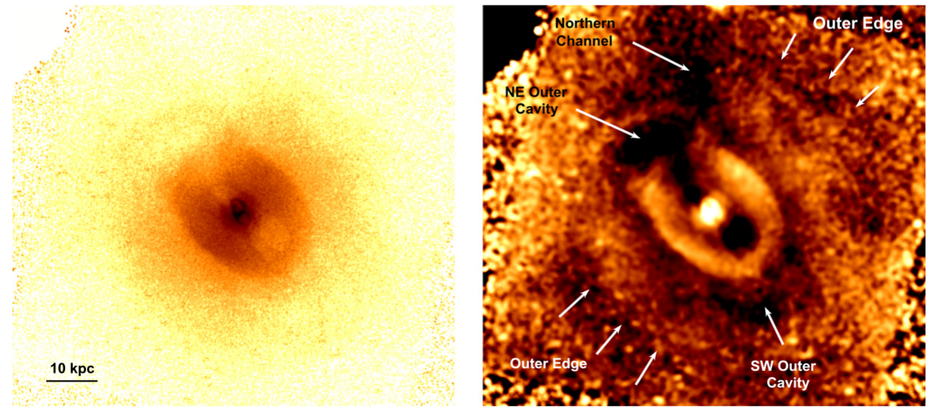
Fig. 4. VHE photon spectrum of HESS J1018–589 for a point-like source at position A (in blue dots and dashed blue line) and derived from a region of size 0.30° comprising the point-like and diffuse emission (in black dots and solid black line). The residuals to the fit are shown in the bottom panel.

Abramowski et al. (2012)

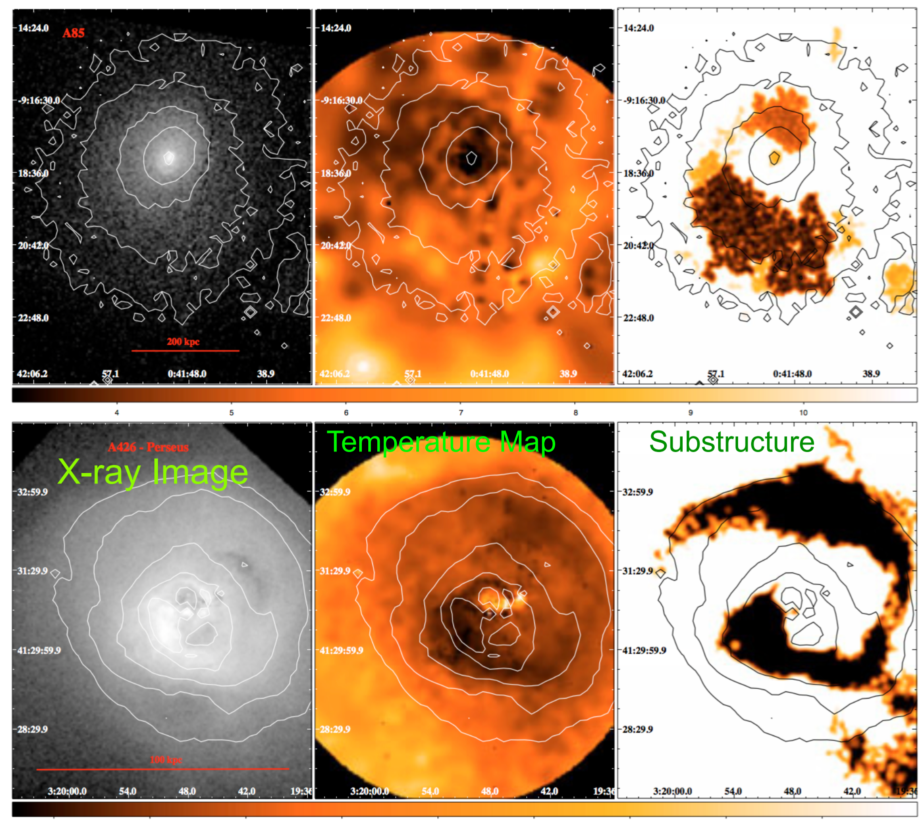
Identifying Substructures in X-ray Clusters



Sanders & Fabian (2012)



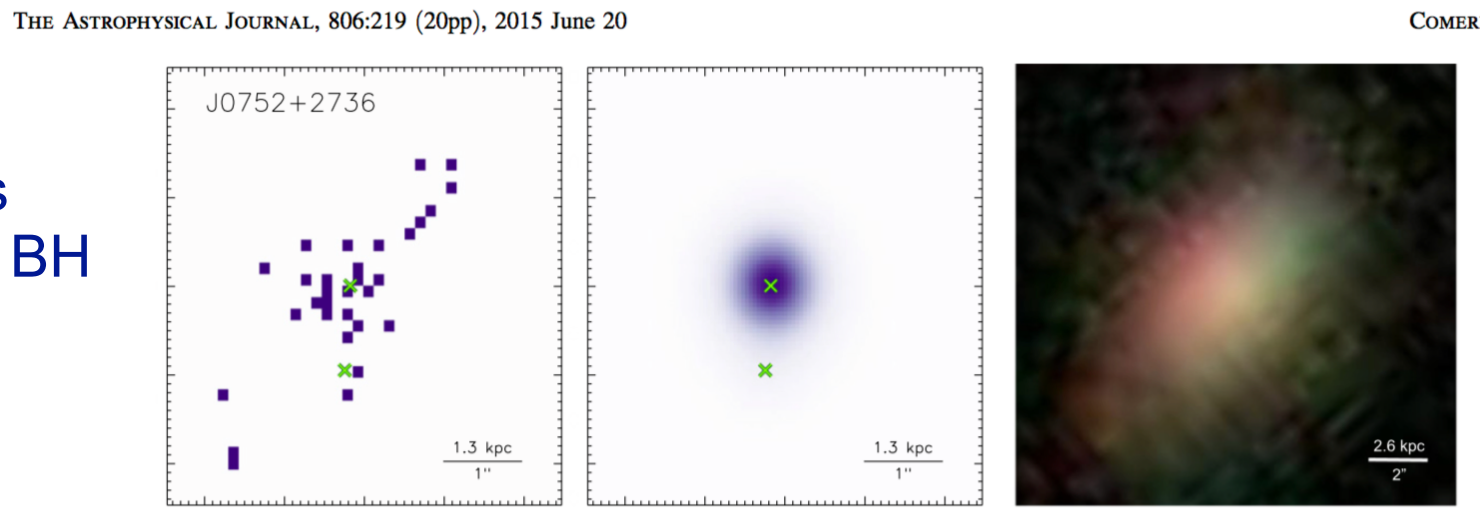
Randall et al. (2015)



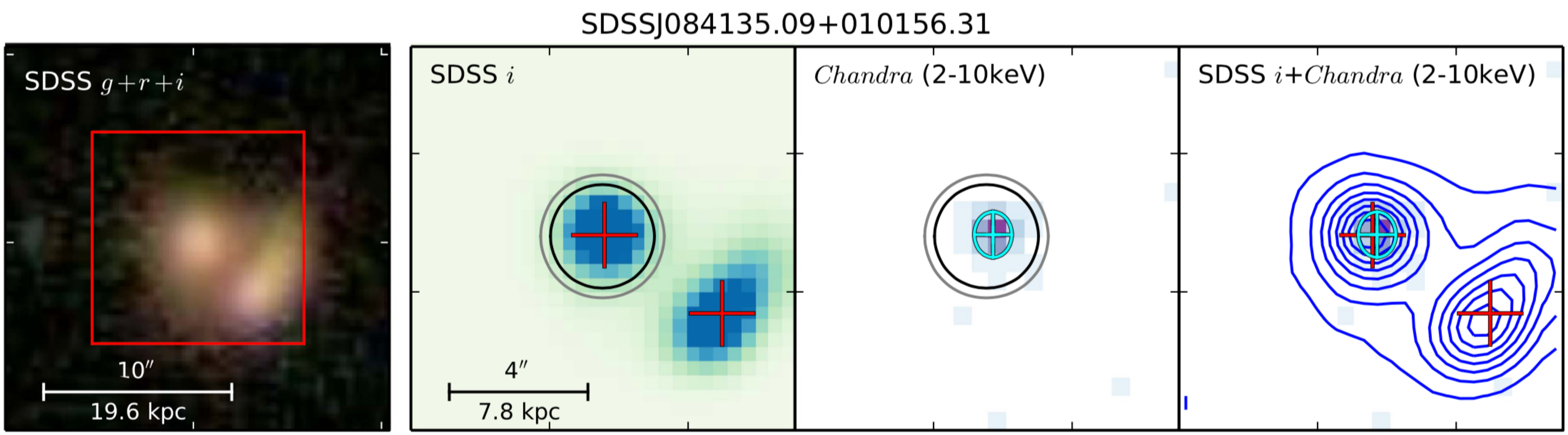
Lagana, Santos & Lima Neto (2010)

Image Analysis

Optical-X-ray offsets
Searches for Binary BH
and GW Recoils



Comerford et al. (2015)



Barrows et al. (2016)

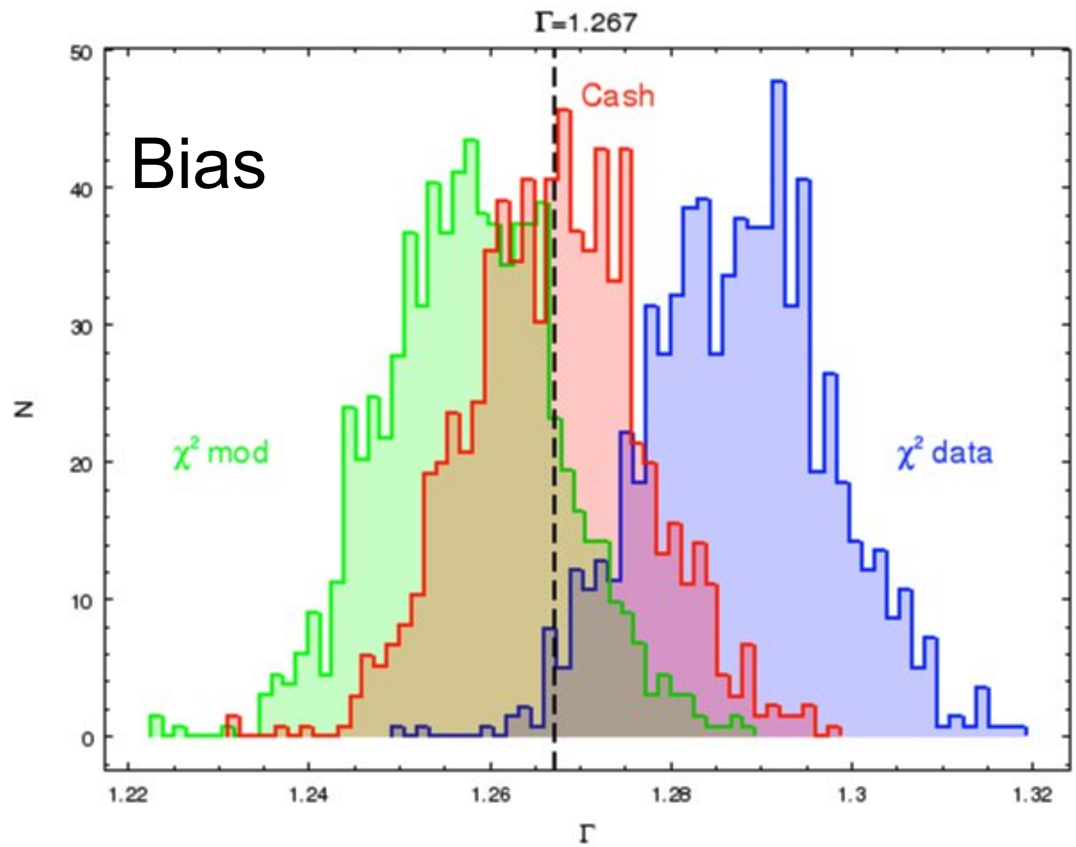
Models & Model Manipulation

- Parameterized models
- Library of models
- User Models can be added (can be ND)
- Model language to build compound model expressions
  - standard operations: +, -, :, x
  - link parameters
  - convolution

Fit Statistics in Sherpa

Fit statistics - math operation on data and model arrays

```
In [19]: list_stats()
Out[19]:
['cash',
 'chi2',
 'chi2constvar',
 'chi2datavar',
 'chi2gehrels',
 'chi2modvar',
 'chi2xspecvar',
 'cstat',
 'leastsq',
 'userstat',
 'wstat']
In [20]: set_stat('cash')
```



"Handbook of X-ray Astronomy " (2011), Arnaud, Smith, Siemiginowska

chi2 statistics as defined by different weights and Poisson likelihood - cash/cstat/wstat

Sherpa, MCMC and Bayesian Analysis

MCMC samplers:

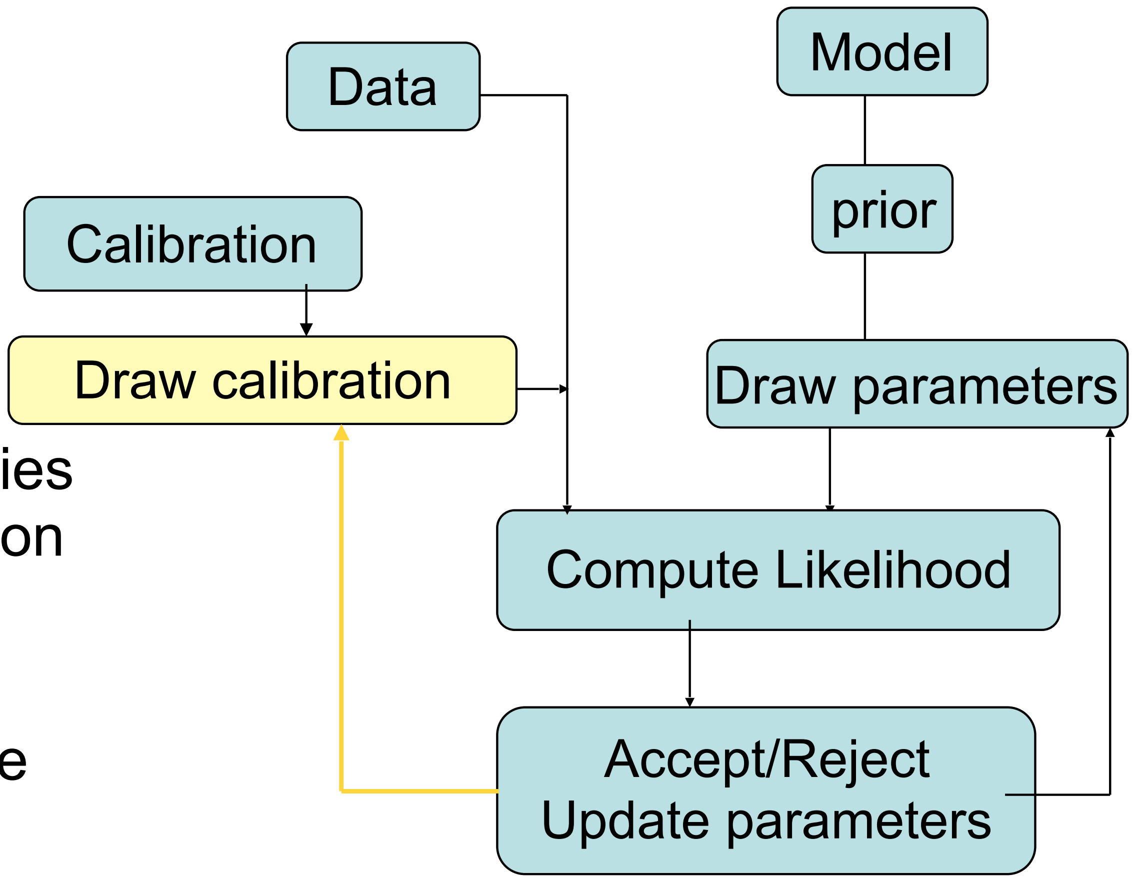
Metropolis and Metropolis-Hastings algorithms

Support for Bayesian analysis with priors.

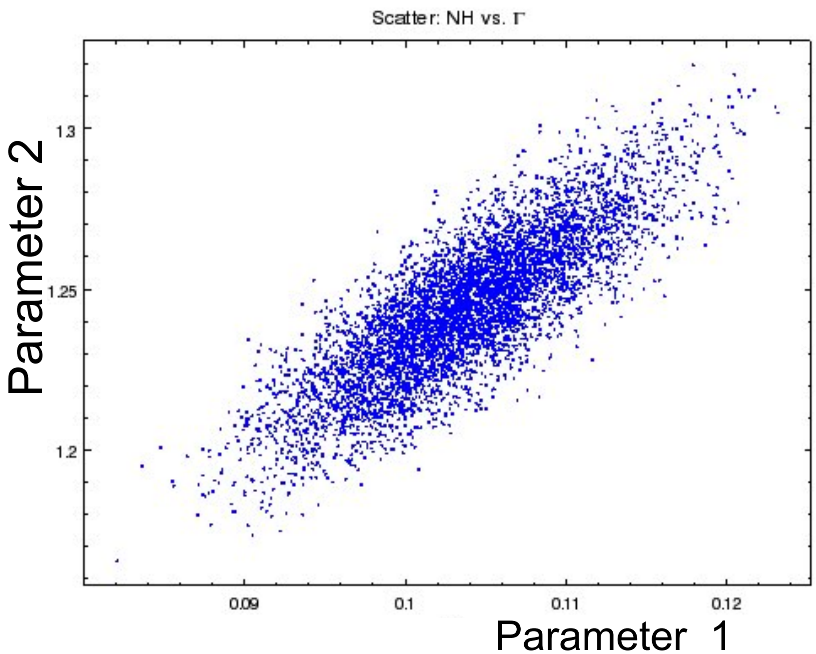
- Explores parameter space and summarizes the full posterior or profile posterior distributions.

- Computed parameter uncertainties can include systematic or calibration errors.

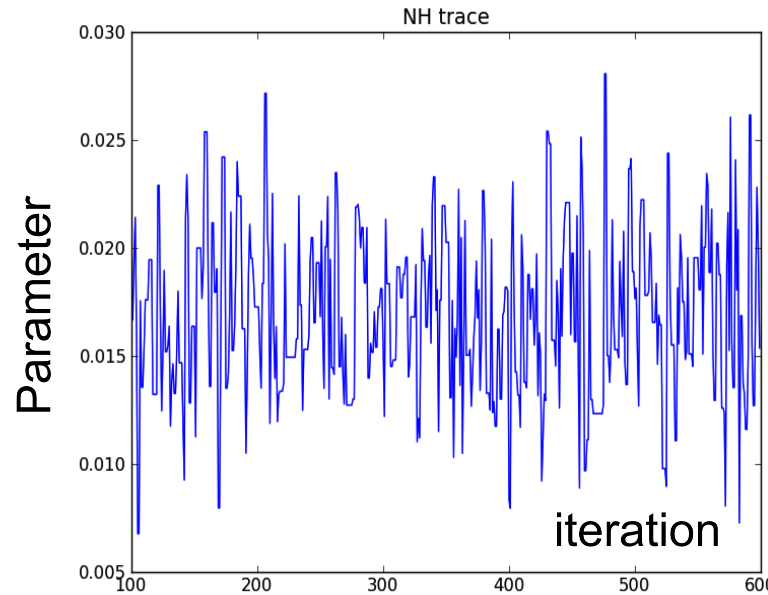
- Simulates replicate data from the posterior predictive distributions.

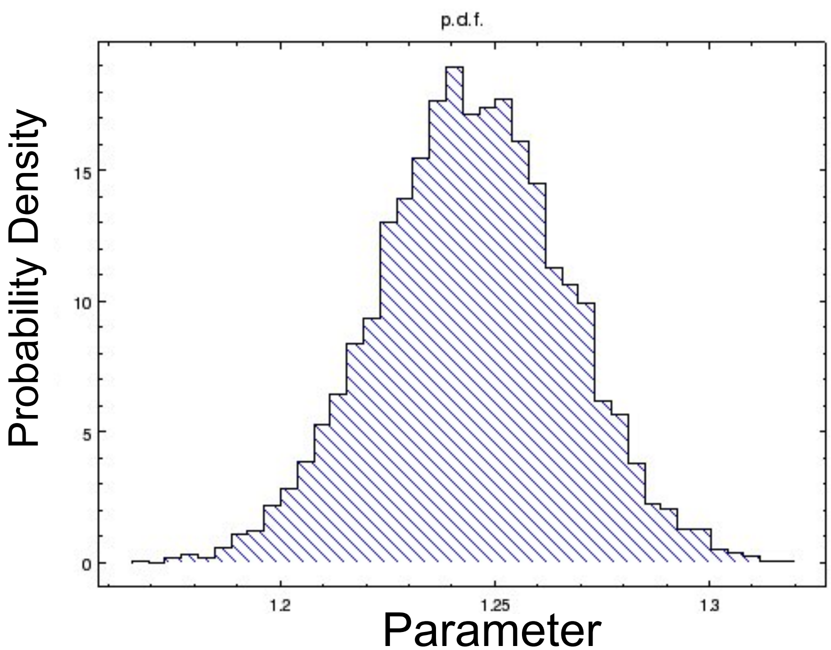


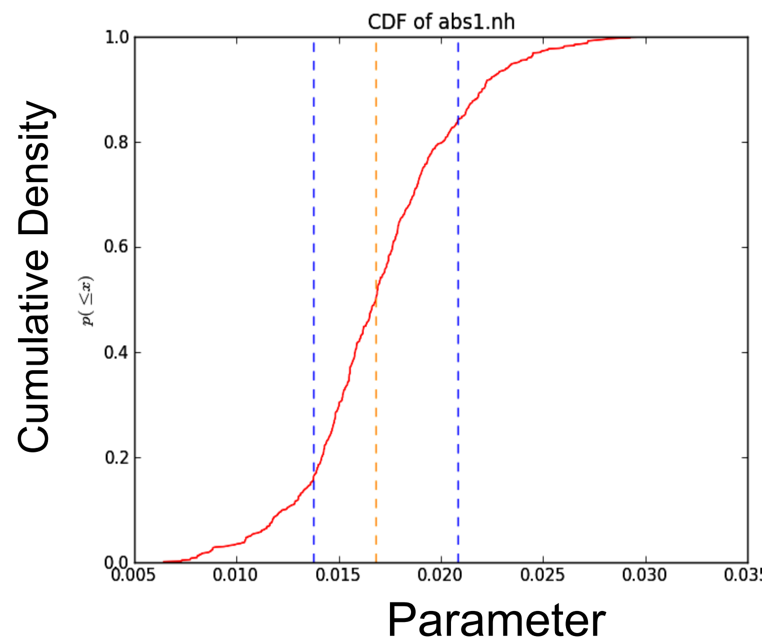
Visualization of the MCMC Results



Trace of a parameter during MCMC run







Optimization Methods in Sherpa

- "Single - shot" routines: Simplex and Levenberg-Marquardt

  start from a set of parameters, and then improve in a continuous fashion:
  - Very Quick
  - Depend critically on the initial parameter values
  - Investigate a local behaviour of the statistics near the initial parameters, and then make another guess at the best direction and distance to move to find a better minimum.
  - Continue until all directions result in increase of the statistics or a number of steps has been reached

- "Scatter-shot" routines: moncar (differential evolution)

  search over the entire permitted parameter space for a better minima than near the starting initial set of parameters.

Sherpa & Python