

Sherpa **Modeling and Fitting**

Aneta Siemiginowska

http://cxc.harvard.edu/sherpa

Chandra/CIAO Workshop at UMass Lowell May 2025



Chandra X-ray Center

Images and videos courtesy of NASA/Chandra/HST unless otherwise noted



Chandra X-ray Center



HARVARD & SMITHSONIAN HARAARD & SMITHSONIAN



DOB NEBI II (

Solar System



Hot gas $> 10^5$ K **Energetic particles**

Quasar Jets



X-ray Images obtained with the Chandra X-ray Observatory (False Color)

X-ray Universe

Supernova Remnants

Clusters of Galaxies



Radio Galaxies





Morphology

Scale and Size

Source Properties

Population



Scientific Measurements

Examples	Methods
point source, diffuse structures, filaments	detection algorithm, smooth unsharp mask, deconvolution model fitting
emission features, boundary, clusters, unresolved structures, mass	surface brightness profiles, exter deconvolution, variability timescal correlation between different ban
flux, luminosity, temperature, abundance, density, obscuration, age	model fit, aperture photome
members, intensity, identification, flux distributions	detection algorithms, hardness r catalog matches, spectral mod







Scientific Measurements



Russell et al 2022

Morphology **Scale and Size Source Properties Populations**



Scientific Measurements

Star Cluster

Chandra X-ray image Red: 0.5-2 keV Blue: 2-7 keV

Townsley et al 2006



Morphology **Scale and Size Source Properties Populations**

NOTE on some Data Issues and Source of Uncertainties:

- combined multiple observations
- background level
- region selection
 - PSF (blurring) impact on source detection
 - overlapping PSFs for source counts measurements



X-ray data

- Counting arriving photons (Poisson counts) different from optical data
- For each photon location on the sky (x,y), arrival time (t) and energy (E) are recorded (x,y,t,E) events
- X-ray observations take a long time a short observation with Chandra X-ray Observatory lasts ~10 ksec (~3 hours) while typical observations take a day or more. The Chandra Deep Field observations took about 23 days.

telescope blurring

Chandra Deep Field North.

https://chandra.harvard.edu/photo/2003/goods/

The faintest sources - one X-ray photon every 4 days!



X-ray Analysis Data Domains

Event $e_i = (x_i, y_i, t_i, E_i)$

• X-ray image is made by binning events into images, e.g. accumulating photons in a selected energy band and fixed exposure time: $e_i(x, y) = \int e(x, y, t, E) dE dt$

- no spectral or temporal information

- analysis require a point spread function

• Energy Spectrum for selected regions are generated by binning the events in energy: $e_i(E) = \int e(x, y, t, E) d(x, y) dt$

- no spatial or temporal information

- require additional calibration files

• Lightcurve - time series for selected region and energy band binning the events in time: $e_i(t) = \int e(x, y, t, E)d(x, y)d(E)$

- no spatial or energy information



Single Domain Analysis

Analysis Domain	Description	Standard Methods
Spectra		
$e(E) = \int e(x, y, t, E) dx dy dt$	only energy, loss of time and morphology	forward fitting, multi-spectra, Poisson likelihood, model and instrument uncertainties
Image		
$e(x, y) = \int e(x, y, t, E) dE dt$	only location and morphology, loss of energy and time	source detections, morphology, contours, image reconstruction, deconvolution
Time variability		
$e(t) = \int e(x, y, t, E) dx dy dE$	only time, loss of energy and source morphology	differences image/spectra, power spectra, periodogram, Bayesian Blocks, flares

X-ray Energy Spectra

- Model fitting:
 - Includes instrument response directly -> lacksquarecalibration impact on the results

Counts (i) =
$$\int R(i, E) A(E) \Lambda$$

- Non-linear astrophysical models, computer generated models
- Appropriate fit statistics, no binning/grouping data, no background subtraction
- Formulations for the Poisson likelihood

M(E) dE



channel

convert matrix (RMF)

keV



X-ray Images

- Chandra X-ray Observatory takes the highest angular resolution X-ray images of the Universe
- Poisson counts sparse images with many empty pixels
- PSF variable across the images cannot be described in an analytical form, the PSF image is a simulation from the computer model of the Chandra mirrors with calibration measurements

$$e(x, y) = \int e(x, y, t, E)d$$

- Some issues:
 - detecting and identifying low surface brightness structures \bullet
 - resolving source in crowded fields overlapping sources, diffuse emission \bullet
 - finding source boundaries
 - PSF uncertainties

Chandra PSF

E dt



http://cxc.harvard.edu/proposer/POG/html/chap4.html#tth_flg4.14





Observations and Data Collection

Astrophysical process





Random number of photons reach the detector



Detector collects photons, adds noise



draw conclusion about the astrophysical source

Scientific Experiment





Instrument specific processing software such as CIAO

Data Analysis:

source detections, source properties, image analysis, features, spectra, physical properties of the source, apply models to understand the source nature

Data Preparation

Conclusions and Final Decision







Modeling and Fitting Software for X-rays

- Sherpa is a modeling and fitting package in CIAO and Python; can fit models to spectra and images.
- X-ray spectral modeling tools:
 - XSPEC
 - ISIS
 - Spex
 - XSPEC

Bayesian X-ray Analysis (BAX) - package for Sherpa and





Sherpa

2D: contours, images







Data Input/Output Astropy.io **PyCrates**

Fit Statistics: Poisson and Gaussian likelihood

Fit Methods: minimization and sampling

Visualization: ds9, matplotlib, bokeh

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Final Evaluation & Conclusions





- X-ray Spectra
 - typically PHA files with the RMF/ARF calibration files
- X-ray Images
 - FITS images, exposure maps, PSF files
- Lightcurves FITS tables, ASCII files
- **Derived** functional description of the source:
 - Radial profile
 - Temperatures of stars
 - Source fluxes
- Concepts of Source and Background data
- Any data array that needs to be fit with a model







Load functions to input data:

data: load_data, load_pha, load_arrays, load_ascii calibration: load_arf, load_rmf load_multi_arfs, load_multi_rmfs background: load_bkg, load_bkg_arf, load_bkg_rmf 2D image: load_image, load_psf General type: load_table, load_table_model, load_user_model

Multiple Datasets - data id

Default data id =1 load_data(2, "data2.dat", ncols=3)

Filtering the data load data expressions notice/ignore commands in Sherpa

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Data in Sherpa

```
<u>Help file:</u>
load_data( [id=1], filename, [options] )
load_image( [id=1], filename|IMAGECrate,[coord="logical"] )
```

Examples: load_data("src", "data.txt", ncols=3)

```
load_data("rprofile_mid.fits[cols RMID,SUR_BRI,SUR_BRI_ERR]")
load_data("image.fits")
load_image("image.fits", coord="world"))
```

```
Examples:
notice(0.3,8)
notice2d("circle(275,275,50)")
```



Models in Sherpa

•	Parameterized models: $f(x)$ absorption - N _H photon index of a power law function - blackbody temperature kT	<i>х_і,р_к)</i> Г
•	Library of models	sherp
		'absor
		'atten'
		'bbody'
		'bbody:

- 'betald',
- 'beta2d',

••••

'blackbody',

- User Models can be added ullet
- Model language to build compound model expressions

ba> list models()

- ptionedge',
- ptiongaussian',
- 1 1
- freq',



Building Models: Expressions

- Standard operations: + * :
- Linking parameters: link()
- Convolution:
 - responses, arf & rmf files via standard I/O
 - **PSF** an image file or a Sherpa model
 - load_conv() a generic kernel from a file or defined by a Sherpa model





Building Models: Examples

- Building composite models:
 - models in the library: e.g. powlaw1d, atten
 - give a name for a model component in the expression: set source(1,'atten.abs1*atten.abs2*powlawld.p1') set_source(2,'abs1*abs2*powlawld.p2')

Building a model expression with convolved and unconvolved • components:

set full model(1,'psf(gauss2d.g2)+const2d.c1')





Building Models: Examples

• Source and Background models:

set_source(2,'xsphabs.abs1*(powlawld.p1+gauss1d.g1)')
set_bkg_model(2,'constld.mybkg')



Fit Statistics in Sherpa

Fit statistics - math operation on data and model arrays

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

Statistic

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



 $\boldsymbol{\theta}_0$





Fitting: Finding Best Model

sherpa-28> fit()

Dataset = 1 Method = levmar Statistic = chi2datavar Initial fit statistic = 644.136 Final fit statistic = 632.106 at function evaluation 13 Data points = 460 Degrees of freedom = 457 Probability [Q-value] = 9.71144e-08 Reduced statistic = 1.38316 Change in statistic = 12.0305 zabs1.nh 0.0960949 p1.gamma 1.29086 0.000707365 p1.ampl

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sherpa-29> print get_fit_results()

datasets = (1,)methodname = levmar statname = chi2datavar succeeded = True parnames = ('zabs1.nh', 'p1.gamma', 'p1.ampl') parvals = (0.0960948525609, 1.29085977295, 0.000707365006941)covarerr = None statval = 632.10587995 istatval = 644.136341045 dstatval = 12.0304610958 numpoints = 460= 457 dof qval = 9.71144259004e-08 rstat = 1.38316385109 message = both actual and predicted relative reductions in the sum of squares are at most ftol=1.19209e-07 = 13 nfev





Fitting: Optimization Methods in Sherpa

Optimization - a minimization of a function:

"A general function f(x,p) may have many isolated local minima, non-isolated minimum hypersurfaces, or even more complicated topologies. No finite minimization routine can guarantee to locate the unique, global, minimum of f(x,p) without being fed intimate knowledge about the function by the user."

Therefore:

- **1.** Never accept the result using a single optimization run; always test the minimum using a different method.
- minimization missed the minimum.
- different parameter values.
- 4. Always check that the minimum "looks right" using a plotting tool.

2. Check that the result of the minimization does not have parameter values at the edges of the parameter space. If this happens, then the fit must be disregarded since the minimum lies outside the space that has been searched, or the

3. Get a feel for the range of values of the fit statistic, and the stability of the solution, by starting the minimization from several





Fitting: 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
 - 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.
- Bayesian sampling methods: Markov-Chain Monte Carlo

Investigate a local behaviour of the statistics near the initial parameters, and then make another guess at



Optimization Methods: Comparison

Example: Spectral Fit with 3 methods

Data: high S/N simulated ACIS-S spectrum of the two temperature plasma **Model:** photoelectric absorption plus two MEKAL components (correlated!)

Start fit from the same initial parameters Figures and Table compares the efficiency and final results



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Method I of	lethod Number of Iterations	
Statistics		
Levmar	31	1.55e5
Neldermead	1494	0.0542
Moncar	13045	0.0542



Nelder-Mead and Moncar fit







Optimization Methods: Comparison



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Sherpa, MCMC and Bayesian Analysis

MCMC samplers in Sherpa: Metropolis and Metropolis-Hastings algorithms Support for the 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.







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.

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Visualization of the MCMC Results



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Final Analysis Steps

- How well are the model parameters constrained by the data?
- Is this a correct model?
- Is this the only model?
- Do we have definite results?
- What have we learned, discovered?
- How our source compares to the other sources?
- Do we need to obtain a new observation?
- ed? ervation?



Confidence Intervals

sherpa-40> covariance()

Dataset = 1 Confidence Method = covariance Fitting Method = neldermead = chi2datavar Statistic covariance 1-sigma (68.2689%) bounds:

Param	Best-Fit Lower Bound Upper Bound
abs1.nH	1.1015 -0.00153623 0.00153623
mek1.kT	0.841024 -0.00115618 0.00115618
mek1.norm	0.699764 -0.00395776 0.00395776
mek2.kT	2.35844 -0.00371253 0.00371253
mek2.norm	1.03725 -0.00172503 0.00172503

sherpa-42> conf()

nek1.kT lower bound: -0.00113811
nek1.kT upper bound: 0.0011439
nek2.kT lower bound: -0.00365452
nek2.kT upper bound: 0.00364805
nek1.norm lower bound: -0.00377224
nek2.norm lower bound: -0.00164417
nek2.norm upper bound: 0.00164816
abs1.nH lower bound: -0.00147622
mek1.norm upper bound: 0.00376011
abs1.nH upper bound: 0.00147268
Dataset = 1
Confidence Method = confidence
Fitting Method = neldermead
Statistic = chi2datavar
confidence 1-sigma (68.2689%) bounds:
Param Best-Fit Lower Bound Upper Bound
·····
abs1 nH 1 1015 -0 00147622 0 00147268
$m_{0}k_{1}k_{T}$ 0.841024 0.00112211 0.0011420
meki.ki 0.041024 -0.00113611 0.0011439
mek1.norm 0.699764 -0.00377224 0.00376011
mek2.kT 2.35844 -0.00365452 0.00364805
mek2.norm 1.03725 -0.00164417 0.00164816

datasets = (1,)sigma = 1 nfits = 103



sherpa-42> print get_conf_results()

```
-----> print(get_conf_results())
methodname = confidence
fitname = neldermead
statname = chi2datavar
percent = 68.2689492137
parnames = ('abs1.nH', 'mek1.kT', 'mek1.norm', 'mek2.kT', 'mek2.norm')
parvals = (1.1015003421601872, 0.84102381214069499, 0.69976355976410642,
2.3584395600380756, 1.0372453037692799)
parmins = (-0.0014762187156509565, -0.001138111192153346, -0.0037722356859711814,
-0.0036545192286010497, -0.0016441656050858455)
parmaxes = (0.001472679745547989, 0.0011439029752089436, 0.0037601110158367312,
0.003648045819133916, 0.001648162229710648)
```



Confidence Regions

sherpa-61> reg_proj(pl.gamma,zabs1.nh,nloop=[20,20])

sherpa-62> print get_reg_proj()

```
\begin{array}{ll} \min &= [\ 1.2516146 & 0.07861824] \\ \max &= [\ 1.33010494 & 0.11357147] \\ nloop &= [20, 20] \\ fac &= 4 \\ delv &= None \\ log &= [False False] \\ sigma &= (1, 2, 3) \\ parval0 &= 1.29085977295 \\ parval1 &= 0.0960948525609 \\ levels &= [\ 634.40162888 & 638.28595426 & 643.93503803] \end{array}
```







Not well-behaved Surface



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Non-Gaussian Shape





Display Posterior Distributions from MCMC

Use corner python package:

https://corner.readthedocs.io/en/latest/





Distributions of Flux and Parameters

Functions: sample_energy_flux, sample_flux

Monte Carlo Simulations of parameters assuming Gaussian distributions for all the parameters Characterized by the covariance matrix, includes correlations between parameters.



* Characterize distributions: plot PDF and CDF and obtain Quatiles of 68% and 95%

sherpa-30> fluxes=numpy.sort(flux1000[:,0])
sherpa-31> a95=fluxes(0.95*len(flux1000[:,0])-1)
sherpa-32> a68=fluxes(0.68*len(flux1000[:,0])-1)

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						Smoot	1				re da	ad backg taset 1:	ground file /var, : 0.00146:14.9504
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Sherpa in DS9 / DAX

••			DA	X Sherpa Model Ec	ditor		
	powlaw1d.mdl1						
	Parameter	Value	Frozen?	Min	<u>Max</u>	<u>Units</u>	
	gamma	1		-10	10		
	ref	1	×	-3.4028e+38	3.4028e+38		
	ampl	0.00011928		1.1928e-07	0.11928		
	xsphabs.abs1						
	Parameter	<u>Value</u>	Frozen?	<u>Min</u>	Max	<u>Units</u>	
	nH	0.2045		0	1e+06	10^22 atoms /	cm^2
Fit		Plot	Conf		Quit	Reset	Ca



000

File Edit Font

read ARF file /var/folders/1c/m66cd7qn0q73ym_z331_g5j80000gp/T//ds9_dax.aneta/sp read RMF file /var/folders/1c/m66cd7qn0q73ym z331 g5j80000gp/T//ds9 dax.aneta/sp read background file /var/folders/1c/m66cd7qn0q73ym_z331_g5j80000gp/T//ds9_dax.a dataset 1: 0.00146:14.9504 Energy (keV) (unchanged) WARNING: No guess found for xsphabs.abs1 WARNING: data set 1 has associated backgrounds, but they have not been subtracte Dataset = 1 = neldermead Method Statistic = cstat Initial fit statistic = 230.373 Final fit statistic = 40.5462 at function evaluation 271 Data points = 36 Degrees of freedom = 34 Probability [Q-value] = 0.203925 Reduced statistic = 1.19253 Change in statistic = 189.826 mdll.gamma 0.643789 0.000188472 mdl1.ampl WARNING: The displayed errorbars have been supplied with the data or calculated

X Spectral Fit

A spectral Fit

```
File Edit Font
```

```
= 189.826
Change in statistic
                  0.643789
  mdll.gamma
   mdll.ampl
                  0.000188472
WARNING: The displayed errorbars have been supplied with the data or calculated
WARNING: data set 1 has associated backgrounds, but they have not been subtracte
mdll.gamma lower bound: -0.0883185
mdll.gamma upper bound: 0.0883185
                                                             0 0 0
mdl1.ampl lower bound: -1.76262e-05
                                                             File Edit Font
mdl1.ampl upper bound: 1.87634e-05
Dataset
                      = 1
                                                                             0.00018
                                                                mdl1.ampl
Confidence Method
                      = confidence
Iterative Fit Method = None
                                                             (powlaw1d.mdl1 * xsphabs
Fitting Method
                      = neldermead
                                                                            Туре
                                                                Param
Statistic
                      = cstat
                                                                ____
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confidence 1-sigma (68.2689%) bounds:
                                                                mdll.gamma
                                                                            thawed
   Param
                    Best-Fit Lower Bound
                                           Upper Bound
                                                                mdl1.ref
                                                                            frozen
   ____
                                                                mdl1.ampl
                                                                            thawed
                    0.643789
   mdll.gamma
                               -0.0883185
                                             0.0883185
                                                                abs1.nH
                                                                            frozen
  mdl1.ampl
                 0.000188472 -1.76262e-05 1.87634e-05
                                                            Photon Flux = 0.00053389
                                                            Energy Flux = 2.84289147
```

WARNING: The displayed e

To restore session, star

restore('/var/folders/1c

Sherpa in DS9 / DAX



XS	pectral	l Fit
- C. N		

38472 -1.76262e-	05 1.87634e-	05		
.abs1)				
Value	Min	Max	Units	
0.643789	-10	10		
1 -3.	40282e+38 3.	40282e+38		
0.000188472 1.	19275e-07	0.119275		
0.2045	0	1e+06	10^22 atoms	/ cm^2
69789672283 pho	oton/cm^2/s			
72629414e-12 er	gs/cm^2/s			
errorbars have b	een supplied v	with the c	data or calcu	lated
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Sherpa Documentation

CIAO



ast modified: 11 December 2024



N	ITRODUCTION
	Home page
	About Sherpa
	Latest Updates
	Sherpa Blog
)	OCUMENTATION
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	Sherpa Snapshot
	Sherpa Threads
	Quick Scripts
	Models
	Statistics
	Optimization Methods
	FAQ
	Known Issues and Limitations
	References
-	elp Pages
	AHELP: Alphabetical
	AHELP: By context

Jsing ahelp ChIPS to Matplot Python Resource

Using Sherpa in a

OWNLOAD SO Download CIAO/S **Contributed Sher** Sherpa Python Pa

HERPA FOR PY Sherpa on GitHuk Sherpa Python Pa



CIAO's modeling and fitting package

WHAT'S NEW | WATCH OUT Analysis Threads | Ahelp | Download CIAO || CIAO | PSF Central

Sherpa is the CIAO modeling and fitting application. It enables the user to construct complex models from simple definitions and fit those models to data, using a variety of statistics a

CIAO 4.17

Sherpa version for CIAO 4.17 was released on December 17, 2024. Sherpa in CIAO runs under Python 3.11 (whether installed using the conda package manager or with ci given in the 4.17.0 and 4.16.1 release notes on GitHub. The major updates were made to plotting, adding the 50 new models in XSPEC 12.14.0, improvements to including li data with asymmetric errors, updates for the experimental bokeh plotting backend, and bug fixes.

More information on this release can be found on the Sherpa updates page.

Sherpa Threads

WHAT'S NEW | WATCH OUT

Top | All | Intro | Scripts | Fitting | Plotting | Statistics | Simulations | Miscellaneous || CIAO | PSFs with ChaRT | Proposal

All threads

A list of all the threads on one page.

Introduction UPDATED

Beginners should start here. The Introductory threads explain how to start Sherpa and provide an overview of using the application.

<u>Scripts</u>

To quickly access the scripts used in each of the Sherpa threads, visit the <u>Sherpa Quick Scripts page</u>.

Fitting UPDATED

Sherpa provides extensive facilities for modeling and fitting data. The topics here range from basic fits using source spectra and responses to more advanced areas, such as simultaneo spatial and grating data.

Before fitting ACIS spectral data sets with limited pulse-height ranges, please read the CIAO caveat "Spectral analyses of ACIS data with a limited pulse-height range."

Plotting UPDATED

Python



🖀 Sherpa

Search docs

INTRODUCTION

Installation

A quick guide to modeling and fitting in Sherpa

Sherpa and CIAO

USER DOCUMENTATION

- What data is to be fit?
- Creating model instances

Evaluating a model

Available Models

What statistic is to be used?

Optimisers: How to improve the current parameter values

Fitting the data

Visualization

Markov Chain Monte Carlo and Poisson data

WORKED EXAMPLES

Utility routines

Simple Interpolation

Comparing Gaussian, Lorentzian, and Voigt 1D models

Simple user model

AN INTERACTIVE APPLICATION

Using Sessions to manage models and data

NOTEBOOKS

Sherpa Quick Start

- Notebook support in Sherpa
- A sample of plots

Axis labelling

- Viewing PHA responses
- Asymmetric errors

EXTRA FUNCTIONALITY

☆ / Welcome to Sherpa's documentation



Welcome to the Sherpa documentation. Sherpa is a Python package for modeling and fitting data. It was originally developed by the Chandra X-ray Center for use in analysing X-ray data (both spectral and imaging) from the Chandra X-ray telescope, but it is designed to be a general-purpose package, which can be enhanced with domain-specific tasks (such as X-ray Astronomy). Sherpa contains an expressive and powerful modeling language, coupled with a range of statistics and robust optimisers.

See also

If you are looking for the similarly named package "SHERPA" for hyperparameter tuning of machine learning models go here: https://parameter-sherpa.readthedocs.io/

Sherpa is released under the GNU General Public License v3.0, and is compatible with Python versions 3.10 to 3.13. Information on recent releases and citation information for Sherpa is available using the Digital Object Identifier (DOI) 10.5281/zenodo.593753.

If you use Sherpa for work/research presented in a publication please cite the Sherpa papers:

Sherpa Paper 2024 (ADS BibTex)

Sherpa Paper 2007 (ADS BibTex)

Sherpa Paper 2001 (ADS BibTex)

The last version of Sherpa compatible with Python 2.7 was the 4.11.1 release.

Introduction

- Installation
- Quick overview
- Requirements
- Releases and version numbers
- Installing a pre-compiled version of Sherpa
- Building from source
- Testing the Sherpa installation
- A guick guide to modeling and fitting in Sherpa
- Getting started
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Published May 13, 2025 | Version 4.17.1



sherpa/sherpa: Sherpa 4.17.1

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wmclaugh Merge #2295 (wmclaugh) -	- update to include release notes f 🚥 🗸 ad45449 · 3 v
.github	Add an interface to ArviZ
docs	Update http -> https
extern	wcssubs autoreconf (auutoconf 2.71)
helpers	XSPEC: support XSPEC 12.15.0
notebooks	doc: add examples of using set_xlabel/ylabel

Sherpa Development on GitHub

- errell 🚨 ; dtnguyen 2 🚨 ;
- luzpaz 2; Christoph Deil⁴ 2;
- ; Katrin Leinweber⁷ ; Todd

https://github.com/sherpa/sherpa

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	Cite this repository -			



Sherpa in the Scientific Python Ecosystem

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 274:43 (9pp), 2024 October



users, are marked with yellow boxes.

Siemiginowska et al.

Figure 11. Sherpa's place in the scientific Python ecosystem. Sherpa requires a numeric library (red box), and interfaces with several optional libraries for I/O, external model libraries, and visualization (blue boxes). It enables the fitting and modeling in several domain-specific packages (white boxes). The two large white arrows mark future implementation of interoperability with astropy.modeling and external optimizers. Infrastructure packages needed for developers, but not

Paper describing Sherpa Python and Open Source Development published in October 2024 in ApJ Supplements

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 274:43 (9pp), 2024 October © 2024. The Author(s). Published by the American Astronomical Society.

OPEN ACCESS

Sherpa: An Open-source Python Fitting Package

Aneta Siemiginowska¹, Douglas Burke¹, Hans Moritz Günther², Nicholas P. Lee¹, Warren McLaughlin¹, David A. Principe², Harlan Cheer¹, Antonella Fruscione¹, Omar Laurino¹, Jonathan McDowell¹, and Marie Terrell¹ Center for Astrophysics | Harvard & Smithsonian, 60 Garden St., Cambridge, MA 02138, USA; asiemiginowska@cfa.harvard.edu ² MIT Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, MA, USA Received 2024 August 23; revised 2024 September 11; accepted 2024 September 15; published 2024 October 11

We present an overview of Sherpa, an open-source Python project, and discuss its development history, broad design concepts, and capabilities. Sherpa contains powerful tools for combining parametric models into complex expressions that can be fit to data using a variety of statistics and optimization methods. It is easily extensible to include user-defined models, statistics, and optimization methods. It provides a high-level user interface for interactive data analysis, such as within a Jupyter notebook, and it can also be used as a library component, providing fitting and modeling capabilities to an application. We include a few examples of Sherpa applications to multiwavelength astronomical data.

Unified Astronomy Thesaurus concepts: Astronomy software (1855)

1. Introduction

Data-processing software developed by astronomical observatories typically generates standard data products which constitute the basis for scientific analysis. Example data products include spectra and images, data cubes, or for the

https://doi.org/10.3847/1538-4365/ad7bab



Abstract

L. Barquín-González et al. 2024; H. Fan et al. 2024), the Hubble Space Telescope (HST; K. S. Green et al. 2023), the Spitzer Infrared Spectrograph infrared telescope (A. Ruiz et al. 2013), Chandra, XMM-Newton, and NuStar in X-rays, the Fermi Space Telescope for high-energy γ -rays (F. Aharonian et al 2024) and HESS for TeV data (H E S S



Sherpa - Summary

- Modeling and fitting application for Python.
- User Interface and high level functions written in Python.
- 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.
- Source code on GitHub <u>https://github.com/sherpa/sherpa</u>
- Open development with continuous integration via Travis

Using Sherpa in Astronomy Research

Recent Examples:

Morphology of Dual AGN in Chandra observations:

GA-NIFS: High number of dual active galactic nuclei at z ~ **3** by Perna et al (2025) doi: 10.1051/0004-6361/202453430



COS1638: (a) Chandra X-ray image overlaid with the red X-ray contours and NIRSpec [OIII] black contours. (b) X-ray Radial Profiles; c) simulated PSF images; (d) Fitting profiles

Model fitting of the Segmented SNR: Bayesian insights into the Tycho supernova remnant: A detailed mapping of ejecta properties by Godinoud et al (2025). doi: 10.1051/0004-6361/202450518



Fitting X-ray Spectra: Long-term X-Ray Variability on the Benchmark

YSO HL Tau by Silverberg et al (2025). doi: <u>10.3847/1538-3881/adb284</u>



XMM EPIC Spectra in six 40 ksec time steps during 2020 campaign

Fitting High Resolution Spectra from Chandra **HETG** Grating



HL Tau Chandra HETG spectra (blue) overlay with the best-fit model (orange). The inserts zoom into the Fe and Si line regions.

Fitting Emission lines in the HST/STIS Spectra: Hubble Space Telescope Observations within the Sphere of Influence of the Powerful Supermassive Black Hole in PKS 0745-191

by Hlavacek-Larrondo et al (2025) doi: <u>10.3847/1538-4357/ada7ed</u>







Sherpa Impact on Astronomy Research

1752 publications in ApJ, AJ, MNRAS, A&A and others use Sherpa (since 2001 and including astro-ph abstracts) https://ui.adsabs.harvard.edu/public-libraries/X6orMXwpRtSPy8x1uiiRMg

486 citations to Freeman et al 2001 SPIE paper
101 citations to Doe et al 2007 ADASS paper on Python implementation
81 citations to zenodo releases: DOI: <u>10.5281/zenodo.593753</u>
7 PhD theses listed in ADS that used Sherpa

176 research papers published in 2024-2025

IMPACT 2001-2025 Statistics from ADS



Sherpa used in research





Confidence Limits on Parameters

Essential issue =>. after the best-fit parameters are found estimate the confidence limits for them. The region of confidence is given by (Avni 1976):



 ν - degrees of freedom α - level χ^2_{min} - minimum

Δ depends only on the number of parameters involved not on goodness of fit

TABLE 1 CONSTANTS FOR CALCULATING CONFIDENCE REGIONS				
(%)	q (No. of Interesting Parameters)			
	1	2	3	
68 90 99	1.00 2.71 6.63	2.30 4.61 9.21	3.50 6.25 11.30	

Aneta Siemiginowska Chandra/CIAO Workshop at UMass Lowell May 2025



